FEASIBILITY OF ONSHORE BALLAST WATER TREATMENT AT CALIFORNIA PORTS

A Study Conducted on behalf of
the California Association of Port Authorities (CAPA)
Pursuant to a Small Grant Assistance Agreement with the
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By

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EXECUTIVE SUMMARY

E-1 INTRODUCTION

The introduction of nonindigenous aquatic species into bays and estuaries is of worldwide ecological and economic concern. Invasive species have become established through a variety of transportation vectors including ballast water discharge. Potential management tools to control the ballast water transport vector include at-sea exchange of ballast water and shipboard and onshore ballast water treatment technologies.

The effectiveness of shipboard ballast water treatment is presently being investigated through pilot studies. However, to date, no onshore treatment studies, focusing on the control of exotic species, have been initiated in the United States. In recognition of this data gap, the California Association of Port Authorities (CAPA) obtained a grant from the United States Environmental Protection Agency (US EPA) to study the conceptual feasibility of onshore ballast water treatment.

The purpose of this study is to assess, at a conceptual level, the technical and operational feasibility of onshore ballast water treatment at public port facilities in California (Figure 1.1) and estimate associated costs, with the objective of evaluating whether further detailed analysis and pilot programs are warranted. To achieve this objective, the following approach was adopted:

- Calculate the ballast water treatment requirements for 11 California public ports based on best-available ballast water discharge estimates;

- Develop conceptual designs for onshore ballast water treatment systems to process the ballast water discharged at each port; and

- Estimate order-of-magnitude costs for the onshore treatment systems, including costs to retrofit vessels, retrofit wharves, construct ballast water storage tanks, construct the treatment facilities and outfalls, and operation and maintenance costs.

E-2 BACKGROUND

Vessel operations require ballast water to maintain stability, increase or decrease draft, and avoid unacceptable structural loads for the purpose of ensuring the safety of crew, ship, and cargo. Ballast water adjustments are made at sea to control draft and stresses on vessel integrity, while approaching shallow water, and in port to control trim and list during cargo loading and unloading operations.

Within North America, pilot studies into the effectiveness of ballast water treatment methods have focused on shipboard systems. The Great Lakes Ballast Water Treatment Demonstration Project has been testing a filtration system on a barge in Minnesota. A two-phase cyclonic/UV system was installed in the cruise ship *P/V Regal Princess* in April 2000, and the Department of Fisheries and Oceans Canada, Vancouver, B.C., is testing the effectiveness of a modular two-phase hydrocyclone/UV system.

Oil terminals off-loading oily ballast water from tankers are required to treat the ballast water to remove oil under Annex I of MARPOL 73/78. A review of onshore oily ballast water treatment facilities in Valdez, Alaska, and drydock facilities in Oregon and San Francisco Bay found that, while it may be possible to convert tanker terminal facilities to handle larger volumes of ballast water, there is little potential for use of drydock ballast water treatment systems.

It is unclear whether existing publicly-owned treatment works (POTWs) could be utilized to treat ballast water. POTWs generally treat wastewater from fresh water sources and saline ballast water in large volumes may be incompatible with fresh water bacteria used in POTWs. Existing POTWs may not have the capacity to handle the very large volumes of ballast water. In addition, potential reuse of treated saline POTW effluent would be limited.

There are exceptional circumstances where use of POTWs may be viable, such as for POTW treatment of small volumes of ballast water, or a POTW which already experiences high salinity loading due to salt water leakage into sewer lines. However, these circumstances are unusual, and in general, the use of existing POTWs is not considered feasible.

E-3 SYSTEM COMPONENTS

The major infrastructure and operational modifications required for an onshore system were identified as:

1. Retrofitting of vessels to allow discharge of ballast water through standardized wharf-side connections;

2. Retrofitting of wharves with piping connections, pumps and force mains to convey ballast water from vessels to onshore storage and treatment facilities;

3. Construction of storage tanks to handle peak discharge flows from multiple vessels that exceed ballast water treatment system flow rates;

4. Construction of ballast water treatment plant(s); and

5. Construction of outfalls to discharge treated water and disposal of solids at a landfill.

Vessel Retrofits

Although bulk carriers, tankers and containerships carry different volumes of ballast water, for the purposes of this study, it was assumed they all have essentially the same ballast water handling requirements. Most existing vessels do not have the capability to pump ballast water to a shore facility at volumes required to prevent vessel delays. Vessels would require the ability to transfer ballast water from either side of the vessel to a shore side facility. The conceptual vessel retrofit design assumed all three classes of vessels would need to lift ballast water vertically 30 meters from the ballast tanks to the main or weather deck at a rate of at least 1,000 metric tons/hour (264,200 gallons/hr).

Total vessel retrofitting costs were estimated to be approximately $400,000. This figure includes design engineering costs for modifying a container or bulk carrier, materials (pumps, piping, valves, etc.) and labor and services. Tankers would generally require more piping and higher discharge rates and would therefore have higher retrofitting costs.

Vessel delays caused by discharging ballast water to an onshore treatment system could lead to increased costs to vessel operators and/or agents. These costs include demurrage, dockage, hire or charter rates, pilotage, and shore-side labor costs, estimated to total up to $70,000 per day at major California ports.

Wharf Retrofitting

All wharves would need piping and pumps installed to transfer ballast water to storage tanks. A mobile collection system would also be required to capture ballast water discharged from vessels approaching port or at anchor. Such a mobile system is not addressed in this study.

Based on the assumed vessel discharge rate, all ports would require 60-centimeter diameter piping to carry ballast water from the vessels to storage tanks. Present costs for materials and basic pipeline installation are approximately $328/meter ($100 per foot). Permitting, pumps and valves, etc., would nearly double the cost to $656/m. It has been assumed that right-of-ways for pipelines could be obtained if necessary. Costs could be significantly higher if right-of-ways cannot be obtained or if environmental issues are encountered.

Ballast Water Storage Tanks

Each port would require ballast water storage capacity equal to the volume of two days of maximum discharge. Available port-specific data on vessel calls and ballast water discharge were analyzed to estimate the required storage capacity and the capacity of the treatment facility required by each port. Individual port records, data collected by the California State Lands Commission and U.S. Coast Guard (USCG) Data (through the Smithsonian Environmental Research Center) were used. The reported discharge volumes may significantly under-represent the actual discharge in some ports. In Addition, most of the available databases include only vessels arriving from outside of the United States Exclusive Economic Zone (U.S. EEZ) (see Figure 1.2) and therefore do not include potentially significant discharges of ballast water from coastal traffic.

All storage tanks were assumed to be constructed of epoxy-coated welded-steel built on slab foundations. The calculated tank dimensions range from eight 58-meter diameter tanks required for the Port of Los Angeles to a single 8.5-meter diameter tank for the Port of Hueneme. Estimated port-specific tank costs range from $20.4 million for the Port of Los Angeles down to $55,000 for the Port of Hueneme (see Table E-1).

Onshore Treatment Facilities

It was assumed that the onshore ballast water treatment facilities would utilize existing technologies of filtration, followed by ultra-violet (UV) irradiation. This combination of technologies was chosen based on proven wastewater treatment performance and on worldwide availability. For onshore treatment to be most effective, it should be available at all port locations.

Filtration would remove particles and organisms down to the 50-micron size. The filtered water would then pass through a bank of UV lamps that emit a UV irradiation dose sufficient to kill or inactivate remaining organisms. The solids/sludge filtered out of the water prior to UV treatment would be thickened either by dissolved air flotation or inclined plate thickening and then dewatered via a plate and frame press.

At the present time, a UV dose standard for the treatment of ballast water has not been established. In lieu of a ballast water standard, the California Wastewater Reclamation criteria, which specifies stringent controls for wastewater reuse, was applied. The standard specifies a minimum UV dose of 140 milliWatt seconds per square centimeter (mWs/cm^2).

Conceptual onshore ballast water treatment facilities were designed for four different treatment capacities.

The capacities considered were 1.0 million gallons per day (mgd) (3,785 MT/day) each for the Ports of Los Angeles and Long Beach, 0.2 mgd (757 MT/day) for the Ports of Humboldt Bay, Oakland, and San Francisco, 0.1 mgd (379 MT/day) for the Ports of Redwood City, Richmond, Sacramento, San Diego, and Stockton, and 0.001 mgd (4 MT/day) for the Port of Hueneme.

Estimated capital costs for onshore treatment facilities (excluding costs for port piping and storage tanks) at specific California ports would range from approximately $1.6 million for the 0.1 mgd facilities for the Ports of Redwood City, Richmond, Sacramento, San Diego, and Stockton, to over $2.2 million for the 1.0 mgd facilities at the Ports of Los Angeles and Long Beach (see Table E-1). A treatment facility was not designed for the Port of Hueneme due to the very small volumes of ballast water involved.

Annual operating and maintenance costs including chemicals, electricity, labor (facility operators), laboratory costs, and landfill disposal costs were calculated for each port. The annual costs would range from $142,000 to $223,000 (see Table E-1).

Outfall And Solids Disposal

The study assumed treated ballast water could be discharged back to the water body in which each port is located. It was assumed that the treated water would be considered benign and that a National Pollutant Discharge Elimination System (NPDES) permit could be obtained from the appropriate Regional Water Quality Control Board (RWQCB). This assumption implies that a ballast water standard would be established so that the RWQCBs could make a determination that the treated water meets accepted standards. The RWQCBs would also need to find that the discharges are consistent with the Regional Water Quality Control Plans (Basin Plans) and Ocean Plans.

It is unknown if fresh water ports such as Sacramento and Stockton would be able to discharge treated ballast water directly to the Sacramento or San Joaquin Rivers because of high salinity in the treated water. Alternative disposal techniques such as transporting the water back to saline waters would need to be considered.

A simple channel outfall or pinch-valve pipe outfall could be designed, permitted, and constructed for approximately $100,000 assuming no environmental impact or mitigation actions would be required. The small volume of solids resulting from filtration could be disposed of at a Class III landfill for approximately $20 per ton.

E-4 DISCUSSION

Technical Feasibility

Onshore treatment of ballast water is technically feasible, provided the technology to achieve current wastewater treatment standards is equivalent to the technology required to treat ballast water for invasive species. It is technically possible to retrofit most vessels to allow for discharge to an onshore facility. It is also possible to retrofit most wharves with connections and piping to transport ballast water to a treatment facility. Storage tanks could be built to accommodate the maximum discharge of ballast water from vessels that would allow for the treatment facility to be designed for an averaged treatment rate. Ballast water could be treated using a combination of filtration and UV irradiation to remove or kill invasive species, provided that the dosage of UV necessary to kill or inactivate ballast water biota is equivalent to that used in existing wastewater treatment facilities. With the possible exception of fresh water ports and ports in water bodies with water quality constraints, treated ballast water could be discharged back to port or nearshore waters, at most port locations, through an NPDES permitted outfall and the resulting solids disposed of at a landfill facility.

Operational Feasibility

After vessel retrofitting, it would be possible for containerships to discharge the ballast water associated with cargo operations at the wharf. The operational feasibility of wharf-side discharge for bulk carriers and tankers is less likely because the discharge volumes and discharge rates required during cargo loading operations for these types of vessels are generally much higher than for containerships. In addition, many bulk carriers discharge ballast water on approach to port to enable faster cargo loading. Constraining these vessels to wharf-side discharge could significantly impact vessel schedules.

Vessels also discharge ballast water when approaching ports to obtain adequate hull clearance in channels or above shallow water hazards. It is not operationally possible to discharge this water directly to an onshore facility. A mechanism to transfer such ballast water to an intermediary vessel would be required. Such required transfer could cause operational delays and could be subject to safety constraints. At-sea transfer of ballast water during rough weather would not be feasible.

Operation and maintenance of ballast water storage tanks and treatment facilities would be operationally feasible. Operation of a seawater outfall would be limited to locations where such outfalls could be permitted and constructed. In locations where outfalls of salt water cannot be permitted because of NPDES constraints (such as fresh water ports), other means to dispose of treated ballast water would need to be considered.

Onshore Treatment Costs

Cost estimates for the five system components of vessel retrofitting, wharf retrofitting, storage tanks, treatment system and waste disposal/discharge were developed for each of the 11 California public ports as described above and summarized in Table E-1. The costs for the four onshore components were added and converted to a cost estimate of treatment cost per metric ton (MT) of discharged ballast water (vessel retrofitting costs do not convert well to this metric). For the 11 California public ports considered, these costs range from $1.40 to $8.30 per MT (see Table E-2). Vessel delay costs and land acquisition costs are not included in these figures.

Other than the cost for open-ocean exchange, there is a paucity of cost data for other ballast water management options – such as shipboard treatment – against which the onshore treatment costs can be compared. The cost for the flow-through dilution method of open-ocean exchange is $0.03 to $0.11 per MT and the cost for full-tank reballasting (empty and fill) exchange method is $0.02 to $0.04 per MT (Dames & Moore, 1999; Oemcke, 1999).

Cost estimates for shipboard filtration/UV and biocide treatment are being developed elsewhere as part of ongoing research and pilot studies. However, at present, a common standard of treatment effectiveness against which ballast water management options can be evaluated does not exist. A ballast water treatment standard is needed before meaningful comparisons of cost-effectiveness can be made.

Worldwide Application

A key consideration in the feasibility of any ballast water treatment option is the viability of applying the system on a worldwide basis. Implementation of unilateral policies on a port or statewide basis would create, in the International Maritime Organization's words, unfair competition between port states. Ballast water treatment requirements should be the same worldwide in order to keep a "level playing field."

E-5 KEY FINDINGS

This study investigated the technical, operational and economic aspects of the onshore treatment option for control of invasive aquatic species. Key findings are:

1. Technically, it would be feasible to retrofit vessels and wharves, construct onshore storage tanks and onshore treatment systems and discharge treated water back to the ocean, provided cost is not a consideration and the treatment standards for existing wastewater

treatment systems can be assumed to be representative of the standards required for organisms in ballast water.

2. It would be feasible to treat ballast water discharged from retrofitted container vessels, but operational delays are likely for bulk carriers and tankers that discharge significant volumes of water while loading cargo. Operationally, it would not be possible to treat all ballast water discharged within the U.S. EEZ at onshore facilities without intermediary vessels or some other transportation system to collect ballast water which, at present, is discharged outside of ports. Safety would be of concern for at-sea transfers of ballast water.

3. Economically, capital infrastructure costs would range from $7.6 million to $49.7 million. Operation and maintenance costs would range from $142,000 to $223,000 per year. Therefore, onshore treatment of ballast water is likely to cost at least $1.40 per metric ton of ballast water treated and as much as $8.30 per metric ton for California public ports, depending on port configuration and discharge volume. For other ports that handle a proportionally larger volume of bulk carrier and tanker traffic, the capital and operations and maintenance costs are expected to be higher. For comparison, the cost of ocean exchange of ballast water, which is currently required for ships entering California from outside the U.S. EEZ is approximately $0.02 to $0.10/MT (Dames & Moore, 1999; Oemcke, 1999).

The development of ballast water treatment technologies is at an early stage. A wide variety of shipboard options using physical and chemical treatment technologies are currently under consideration. Given the stage of development of ballast water treatment options, it is too early to consider significant investment in the onshore treatment option.

1.01 INTRODUCTION

The introduction of nonindigenous aquatic species into bays and estuaries is of worldwide ecological and economic concern. Invasive species have become established through a variety of transportation vectors including ballast water discharge. Previous studies have provided an overview of the ballast water issues and potential management tools including the at-sea exchange of ballast water recommended by USCG and International Maritime Organization (IMO) guidelines and required by California (Carlton et al, 1995; Oemcke, 1999; Dames & Moore, 1999).

Shipboard and onshore treatment of ballast water has been proposed as a means to control the introduction of non-indigenous species. Pilot programs investigating shipboard treatment are underway in the Great Lakes and in Vancouver, Canada. However, no onshore treatment pilot programs focusing on the control of exotic species have been initiated to date[1]. In recognition of this knowledge gap, the California Association of Port Authorities (CAPA) obtained a grant from the United States Environmental Protection Agency (US EPA) to study the conceptual feasibility of onshore treatment of ballast water.

The purpose of this study is to assess at a conceptual level the technical and operational feasibility of onshore ballast water treatment at public port facilities in California (Figure 1.1) and to estimate the associated costs, with the objective of evaluating whether further detailed analysis and pilot programs are warranted. To achieve this objective, the following approach has been adopted:

- Calculate the ballast water treatment requirements of various California ports based on best available ballast water discharge data;

- Develop conceptual designs for onshore ballast water treatment systems and associated retrofitting needed to handle the discharge volumes and rates for each port; and

- Estimate order-of-magnitude costs for the onshore treatment system, including:

    – Costs of vessel retrofitting to allow pumping ballast water ashore;

    – Costs to construct ballast water storage tanks;

    – Costs to retrofit wharves with piping to transfer ballast water from vessels to the

[1] Onshore treatment of ballast water for conventional pollutants does occur, (see Section 2.1).

treatment facility (reticulation costs);

- Capital costs to construct the treatment facilities;
- Operation and maintenance costs;
- Costs to construct outfalls; and
- Potential additional costs to shipping lines due to vessel delays.

In order to evaluate the technical and operational feasibility of onshore treatment, the following central questions should be evaluated:

Technical Feasibility:

Is it technically possible, irrespective of cost, with the use of existing technology, to process ballast water at an onshore treatment facility at volumes and rates currently discharged at California ports?

Operational Feasibility:

Can all ballast water presently discharged within the 200 mile U.S. EEZ and/or 2,000-foot water depth criteria be discharged to onshore treatment facilities without causing significant delays to vessel operations or compromising vessel safety?

Associated Costs:

The development of both shipboard and onshore treatment alternatives is at an early stage. As a result, a treatment standard has not been established making meaningful comparisons of the costs of treatment options difficult. Hence, economic feasibility is not analyzed in this study. Specific questions that need to be addressed in future studies include:

1. Is it cost effective to treat ballast water onshore compared with alternative treatment methods and management tools, including those under development?
2. Is it reasonable to expect vessel operators would continue to utilize such a system if more cost effective technological or management tools were developed?
3. Is it realistic to expect such a system could and would be installed on a nationwide or worldwide basis such that ballast water treatment does not become an economic deterrent

against countries/states/ports implementing such treatment?

Question #2 addresses the stage of development of new technologies and the problem of when to invest in any one of the options. Is it possible that a new technology such as a "magic bullet" biocide or operational changes would render the capital investment in an onshore system worthless? If a treatment system involves significant capital expense, what is the probability that the investment would be lost?

Question #3 is based on the "level playing field" concept of competition between various ports and countries. Ideally, environmental protection controls should apply equally worldwide, as is recognized in the IMO guidelines.

Report Outline

Section 2 of this report presents a brief overview of the current state of onshore ballast water treatment and research. Section 3 presents the study approach. Section 4 presents data, calculations, and findings for the five components of onshore treatment; vessel retrofitting, wharf retrofitting, construction of ballast water storage tanks, construction and operation of ballast water treatment facilities, and construction of outfalls. A discussion of the general feasibility of onshore treatment and the specific feasibility for California's public ports is presented in Section 5. Section 6 presents conclusions.

1.04BACKGROUND

Vessel operations require ballast water to maintain stability, increase or decrease draft, and avoid unacceptable structural loads to ensure the safety of crew, ship, and cargo. Ballast water adjustments are made at sea to control draft and minimize stresses on the vessel, in entrance channels to reduce draft in shallower water, and in port to control trim and list during cargo loading and unloading operations.

Ballast water capacities and discharge rates vary widely between vessel types. Large tankers can carry up to 200,000 metric tons (MT) of ballast water (approximately 40% of their deadweight tonnage (DWT) or cargo carrying capacity). Tankers usually operate a one-way trade pattern, carrying cargo in one direction and returning in ballast. Tankers discharge ballast water at rates of up to 20,000 MT per hour (NRC, 1996). Containerships typically carry lower percentages of ballast water related to DWT (30%) (AQIS, 1994). They generally engage in two-way trade and discharge ballast water at lower rates of 1,000 to 2,000 MT per hour (NRC, 1996). Bulk carriers are intermediate, carrying approximately 30% to 40% of their DWT in ballast water (up to 90,000 MT of ballast water) and discharging at rates of 5,000 to 10,000 MT per hour.

Unmanaged ballasting and deballasting operations have contributed to the introduction of exotic nonindigenous species into coastal waters and estuaries worldwide (Carlton et al., 1990, 1995; Cohen & Carlton, 1995, Nichols et al., 1990; MacDonald & Davidson, 1998). Past and potential ecological and economic impacts of such introductions have lead to international, national, regional, and state regulations and guidelines, which attempt to control nonindigenous species introductions resulting from ballast water discharge.

At present, most regulations and guidelines focus on offshore ballast water exchange to prevent the discharge of potentially invasive species in nearshore waters. The cost for the flow-through dilution method of open-ocean exchange is $0.03 to $0.11 per MT and the cost for full-tank reballasting (empty and fill) exchange method is $0.02 to $0.04 per MT (Dames & Moore, 1999; Oemcke, 1999). However, exchange is only partially effective due to safety concerns, which may override exchange at times, as well as effectiveness of the actual exchange (Dames & Moore, 1999). Other potential ballast water management and treatment options include various shipboard chemical and physical treatment methods, ballast water micro-management, retaining ballast onboard, risk-based management, and treatment onshore (Dames & Moore, 1999; Oemcke, 1999; Oemcke & van Leeuwen, 1998).

Within North America, pilot studies into the effectiveness of ballast water treatment methods have focused on shipboard systems. The invasion of the Great Lakes by the zebra mussel, native to the Baltic Sea, was a key factor in the development of the current U.S. invasive species legislation. To investigate possible shipboard control of introductions, the Great Lakes Ballast Water Treatment Demonstration Project, managed by the Northeast-Midwest Institute has been testing a filtration system on a barge in Minnesota. The system uses self cleaning filters and has been tested down to pore sizes of 50 microns and flow rates of up to 350 MT/hr (1,500 gpm). There are plans to add an UV irradiation phase to the system this summer (T. Marley, *pers. comm*.).

Hyde Marine, Inc. of Cleveland, Ohio installed a two-phase cyclonic/UV system on the cruise ship P/V *Regal Princess* in April 2000. The system can treat up to 200 MT/hr. The filters remove material larger than 40 microns that has a specific gravity greater than that of seawater. The UV system then irradiates the filtered water with a dose of 130 mWs/cm^2. This system is designed to disinfect ballast water during ballasting so that the separated solids can be discharged back to the source waters. Approximately 10% of ballast water is returned to the source with the solids (T. Marley, *pers. comm*.).

The Department of Canadian Fisheries and Oceans Canada, Vancouver, B.C., is testing the effectiveness of a modular, ship-based, two-phase hydrocyclone/UV system developed by Velox Technologies Inc., of

Calgary, Alberta. As with the Hyde Marine system, the hydrocyclone separates material with a specific gravity greater than that of seawater. UV radiation is used to kill or inactivate organisms remaining after filtration. A range of dosages and frequencies are required to inactivate various taxa. Fisheries and Oceans is studying the effectiveness of the system as measured by organism mortality rather than removal. They are testing a 300 MT/hr Velox system on a variety of organisms including mussels, clams and dinoflagellates (T. Sutherland, *pers. comm*.).

Velox Technology estimates that the equipment capital cost for a hydrocyclone/UV system 10 times the size of the Vancouver system – one with a capacity of 3,000 to 4,000 MT/hr – would be less than $500,000 (W. Hesse, *pers. comm*.). Such a system would also have the primary objective of mortality rather than removal. The reject phase is run through the system again to achieve the highest possible mortality rate. Although UV acts by damaging an organism's DNA, some organisms such as algae undergo photo-repair of damaged DNA in the presence of light (Levine & Thiel, 1987). Because the system would be operated during ballasting, any irradiated organisms passing the UV lamps would remain in ballast tanks, thereby reducing the possibility of photo-repair.

4.1 EXISTING ONSHORE BALLAST WATER TREATMENT SYSTEMS

Some tanker terminals and drydocks have water treatment systems that process ballast water for chemical or physical pollutants before discharge to nearby surface water. Oil terminals receiving oily ballast water from tankers are required to have treatment facilities for the removal of oil from the ballast water under Annex I of MARPOL 73/78. Once the oil has been removed, the treated water can be discharged. It has been suggested that such facilities could also be used to treat ballast water for invasive species from other types of ships. This section reviews three existing onshore treatment facilities – none of which were specifically designed to remove invasive species from ballast water.

Alyeska Pipeline, Valdez, Alaska

The Alyeska ballast water treatment system receives ballast water from tankers emptying non-segregated ballast water tanks (ballast water carried in cargo tanks) prior to loading crude oil in the same tanks. The three-step treatment process to remove oil includes gravity separation, dissolved air floatation, and biological treatment designed to remove soluble aromatics remaining in the water after the first two steps.

While the treatment system was not designed to remove or kill non-indigenous species, live organisms have not been found in the discharge from the plant. Mortality of organisms is attributed to the natural toxicity of the soluble oil compounds in combination with low dissolved oxygen resulting from high chemical oxygen demand in the non-segregated tanks (J. Kling, *pers. comm.*). The facility has made initial investigations into the possibility that it could be used to treat both segregated and non-segregated ballast water through the addition of a biological treatment unit. The outstanding questions are whether the system has the capacity to handle significantly larger water volumes and the form and effectiveness of the biological unit.

Cascade General Drydock, Portland Oregon

Cascade General is a large drydock facility on the Columbia River in Oregon. The facility has two ballast water treatment plants. The first treats non-segregated ballast water. Tanker ballast water is pumped to an oil-processing facility where it undergoes steam and gravity separation. The resulting water is discharged under a NPDES permit. The system has a storage capacity of 8 million gallons. The second system treats segregated ballast water discharged from a vessel's tanks into the drydock during repairs. The water undergoes clarification and flocculation to treat for metals and turbidity. The water is then neutralized to control pH and the resulting water is discharged under the NPDES permit. Neither system is designed for or could be used to treat ballast water for invasive species (A. Sprott, *pers. comm.*).

San Francisco Dry Dock, San Francisco, California

San Francisco Dry Dock Inc. (SFDD), located in the Port of San Francisco, performs services including ship repair (painting, abrasive blasting, hydroblasting, fabrication of parts, and cleaning of tanks onboard vessels). Discharges from the facility to central San Francisco Bay include ballast water from the floating dry docks and stormwater associated with industrial activity at the facility.

Ballast water waste from SFDD includes ballast water from the vessels being serviced. Because this water is potentially contaminated with chemical additives, oil and grease, particulates, and invasive species, discharge into San Francisco Bay is prohibited. Additional ballast water waste of approximately 30 million gallons is discharged from Dry Dock #1 for every dry dock evolution. This water is used to submerge the dry dock in order to bring in vessels. Because these ballast tanks are enclosed and no chemical additive is used, the floating dock ballast water is a discharge of Bay water and is permitted.

The California Regional Water Quality Control Board (RWQCB) for the San Francisco Bay Region issued a Waste Discharge Requirements Order for a NPDES Permit for SFDD in May 1999. The Order allowed SFDD until January 1, 2000 to apply for a Pre-Treatment Permit with the City of San Francisco for the discharge of vessel ballast water to the San Francisco sewage treatment system. SFFD appealed the prohibition on the discharge of ballast water and sediments to the Bay, as their publicly-owned treatment works (POTW) treatment permit prohibits them from discharging saline water except in small quantities to the POTW and the prohibition was stayed (S. Moore, San Francisco RWQCB, *pers. comm.*).

As discussed in Section 3, discharge of ballast water to POTWs is unlikely to be a viable treatment option for most ports.

4.2 PREVIOUS ONSHORE BALLAST WATER RESEARCH

AQIS Research

The Australian Quarantine and Inspection Service (AQIS) is the lead agency for the management of ballast water issues in Australia, including policy development, implementation of a strategic research plan, and quarantine operations. AQIS investigated the feasibility of onshore treatment using UV disinfection (AQIS, 1993a). A conceptual facility was designed to treat the ballast water from three 140,000 metric ton (MT) bulk carriers per week, assuming 45,000 MT (11.9 million gallons) per carrier. The design assumed a ballast pump capacity of 4,000 MT/hr (1.06 million gallons per hour or 17,600 gallons per minute). With a storage facility capacity of 50,000 MT (132,000 gallons) a treatment plant capacity of approximately 800 MT/hr (210,000 gallons/h) would be required. This is approximately one fifth of the required capacity for the treatment plant if only nominal storage were provided.

The study included treatment costs (construction, operation and maintenance costs), but did not include the cost of land for the facility, costs for vessel retrofitting to allow pumping ballast water ashore, or costs to install pipes from the wharves to the facility. The study concluded that further research was necessary including research on disinfection options, costs, effectiveness, and impacts to shipping lines. When the AQIS study was originally published, it was generally thought that a cost effective onshore treatment facility could be developed. However, subsequent research by AQIS has indicated that onshore treatment is probably too expensive a treatment option for Australian ports (P. Lockwood, AQIS, *pers. comm.*).

Canadian Coast Guard

In 1992, Pollutech prepared a report for the Canadian Coast Guard, evaluating various ballast water treatment and management options. The analysis included onshore treatment as an option and concluded that it may be feasible. Costs for portions of this option were developed by the Victorian Parliamentary Commission into Ballast Water (ENRC, 1997). They concluded that, for some ports where wharves are not widely spread and where available land is inexpensive, onshore treatment could be economically feasible. However, the study estimated extremely low costs for retrofitting vessels and did not consider all costs associated with onshore facilities (for example, wharf piping), which compromises the validity of the conclusions.

1.05 STUDY APPROACH

To investigate the feasibility of onshore treatment of ballast water at California ports, current ballast water practices were compared with a scenario in which vessels discharge all ballast water to wharf-side connections during cargo loading or unloading. Rather than discharging ballast water overboard as is the present practice, vessels would pump ballast water to the wharves where it would be piped to storage and treatment facilities. The treated water would be discharged back to the port waters and the solids would be disposed of at a landfill.

The major infrastructure and operational modification components required for such an onshore system include:

1. Retrofitting of vessels to allow discharge of ballast water through standardized wharf-side connections;

2. Retrofitting of wharves with piping connections, pumps and force mains to convey ballast water from vessels to onshore storage and treatment facilities;

3. Construction of storage tanks to handle peak discharge flows from multiple vessels;

4. Construction of ballast water treatment plant(s); and

5. Construction of outfalls to discharge treated water and disposal of solids at a landfill.

Several key assumptions are built into the onshore treatment scenario analyzed in this study. They include the assumption that the onshore system would only treat ballast water discharged at the wharves. A separate system may be required to capture and transport ballast water discharged during the approach to coastal waters or to reduce draft in shallow channels or ports. Such an off-loading system has not been included in this analysis.

It is unclear whether existing publicly-owned treatment works (POTWs) could be utilized to treat ballast water. POTWs generally treat wastewater from fresh water sources and saline ballast water in large volumes may be incompatible with fresh water bacteria used in POTWs.

It has been assumed for the purposes of this study that use of existing wastewater treatment systems such as POTWs to treat ballast water is not generally possible and construction of new ballast water treatment plants would be required. There are two reasons for this assumption, 1) The concentration of salts in sea water (30,000 to 35,000 ppm) would kill fresh-water bacteria used in most POTWs, and 2) due to water conservation goals, POTWs seek to reuse processed wastewater for industrial uses or irrigation. Water quality objectives for wastewater reuse depend on the intended use but are generally less that 200 ppm chloride (R. Nuzum, *pers. comm.*).

There are exceptional circumstances where use of POTWs may be viable, such as for POTW treatment of small volumes of ballast water, or a POTW which already experiences high salinity loading due to salt water leakage into sewer lines. These conditions exist in San Francisco, where the local POTW treats water with elevated salinity and the volumes of ballast water to be treated are small relative to the total volume of water treated at the POTW.

The San Francisco Estuary Institute (SFEI) and the City of San Francisco investigated the possibility of ballast water treatment at the Southeast Water Pollution Control Plant and concluded that treatment may be possible. Whether the level of salt is high enough to cause problems depends on a number of factors, which were not analyzed in the SFEI study. These include: (a) the salinity of the ballast water (which may vary considerably from ship to ship, and possibly from shipping route to shipping route), (b) the relative volumes of ballast water being discharged and of POTW influent (which vary considerably between ports and POTWs), (c) the POTW's operational and output requirements (which may also vary significantly), and (d) the ballast treatment application (will all of the ships' ballast water be treated; will only ballast from overseas be treated; will onshore treatment be used only as a back-up when weather or other factors prevent mid-ocean exchange, etc.). The circumstances at San Francisco are unusual, and in general, the use of existing POTWs is not considered feasible.

It may be feasible to modify existing non-segregated oily-water ballast water treatment systems to handle segregated ballast water (see Section 2.1). However, most public ports do not have such systems in place and construction of new ballast water treatment facilities would be required.

The key assumptions for each component of the onshore system are as follows:

1. Vessel Retrofitting

a) Vessels would pump ballast water from tanks to wharf-side connections;

b) All vessels would have standardized connections; and

c) The rate of ballast water discharge would closely approximate cargo loading rates to avoid delays.

4. Wharf Retrofitting

a) All or most of a port's wharves would be connected to the treatment system;

b) The piping system would have capacity to accommodate peak vessel discharge rates; and

c) Right-of-ways could be obtained for pipelines.

4. Storage Tanks

a) Tanks would have the capacity for two days' peak discharge volume;

b) Standard above-ground epoxy-coated steel tanks would be used; and

c) Foundation engineering for seismic issues in soft soil conditions would not be required.

4. Ballast Water Treatment System

a) The system would have a capacity equal to the average discharge volume per day (see Section 4.3);

b) Currently available filtration and UV irradiation technology would be used;

c) In lieu of a specific ballast water treatment standard, the treatment standards for wastewater can be assumed to apply; and

d) Solids would comprise 10-50 mg/L of the ballast water (roughly equivalent to solids density in secondary treated water).

5. **Discharges: Outfall and Solids Disposal**

a) Disinfected ballast water would be discharged back to the ocean or port waters though an NPDES permitted outfall; and

b) Solids would be disposed of at a Class III landfill.

1.03SYSTEM COMPONENTS

Specific assumptions for each system component and details of each system component are presented in the following sections.

3.1 VESSEL RETROFITTING

At present, most vessels take on ballast water through sea chests; open boxes generally located near the bottom of the ship and connected to valves and ballast water intake/discharge pipes. The sea chests are usually fitted with grates to prevent the uptake of debris. The intake/discharge pipe leads to the ballast water pump. Most ships have one or two large dedicated pumps (generally 500 to 3,000 MT/hour) (Herbert, 1999). Ballast water is pumped through the ballast water main, either one large trunk pipe branching to each ballast tank, or individual pipes to individual tanks, with remotely operated valves for each tank.

During deballasting, water is usually discharged through valves located in the hull or back through the sea chests. Presently, most vessels do not have the ability to discharge ballast water to onshore facilities and would require modifications to pumps and piping to allow such operations.

Differences in vessel design and construction, even within a single type of vessel, make simple characterization of vessel ballast water systems difficult. For the purposes of this study, a generalized conceptual ballast water system was developed based on a figure from *Marine Engineering* (Society of Naval Architects and Marine Engineers, 1992). The original ballast and bilge water piping diagram is presented as Figure 4.1. The schematic ballast water diagram of an existing system developed from Figure 4.1 is shown as Figure 4.2. A conceptual system for retrofitted vessels is presented in Figures 4.3 and 4.4. Figures 4.2, 4.3 and 4.4 are very general and do not show the metering, controls, ancillary valves, filters, regulators, safety devices or other equipment that would be required in actual shipboard installations.

The vessel retrofitting analysis is based on the following assumptions:

- Although bulk carriers, tankers and containerships carry different ballast water volumes, they all have essentially the same ballast water handling requirements;

- The conceptual existing system presented in Figure 4.2 is representative of ballast water systems aboard containerships, bulk carriers, and tankers, (even though, as stated above, such a characterization is extremely difficult.)[2];

- The differences between the three classes of vessels are primarily those of size, with the capacity of container vessels roughly half that of bulk carriers and tankers (See Footnote 1);

- Vessels have two parallel ballast water systems that can be cross connected. (Figures 4.2 and 4.3 show only one, essentially half the system.);

- Vessels do not have the capability to pump ballast water to the main or weather deck at volumes required to prevent vessel delay with the currently installed pumps and piping systems. As shown in Figure 4.3, a hose would have to be run from the hose connection up to the main or weather deck and over the side;

- Vessels require the ability to berth on the port or starboard side and, hence must be able to transfer ballast water to a shore side facility on both sides; and

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[2] The location of the on-board shore connections will be different for bulk carriers and containerships than for tankers and tankers will generally require more piping to complete the modification. As indicated on Figure 4.3, the new 'off-ship ballast water line' will originate at the existing below deck port-starboard ballast crossover line and run up to the main deck, where it will then tee and run to both the port and starboard shore discharge connections. On a tanker, the ballast water discharge shore connection will most likely need to be located at the mid-ships cargo loading/discharge manifold; whereas, for containerships and bulk carriers the most appropriate location would be the bunkering (fueling) station, which is located in the aft quarter of the ship. Making the general assumption that the ballast pump crossover is located near the engine room, the pipe length required to run to the shore connection for containerships and bulk carriers should be significantly less than that for tankers.

- All three classes of vessels will have to lift ballast water from the ballast tanks vertically 30 meters (the height from the bottom of ballast tanks to the main or weather deck) to discharge to a shore facility.

To enable existing vessels to pump ballast water to shore-based facilities, existing ballast water pumps would have to be replaced with higher capacity pumps, new piping would be installed to the main or weather deck, and a manifold would be installed at that deck to allow connection to the shore facility. This new system is shown in Figure 4.3. This system is designed to prevent vessel delays due to ballast water transfer operations and utilize as much of the existing system as possible.

With existing systems, transferring ballast water from the ballast tanks to a shore facility requires that a hose be connected and run to the main or weather deck and over the side to a shore-side reception facility and the ballast water pump must be operating. Operation of the conceptual system is identical except that rather than being pumped through a hose, the ballast water would be pumped through installed piping to an installed manifold to which the shore-side facility would be connected (Figure 4.3). If necessary, both ballast water pumps could be run in parallel, doubling the vessel's ballast water flow rate.

7.0.1 Vessel Modification Costs

Required vessel modifications would include the following:

1. Removal of existing ballast water pumps, motors, foundations, control valves, strainers, controllers, wiring and associated instrumentation [3];

2. Fabrication and installation of new ballast water pump foundations and main or weather deck overboard manifolds (port and starboard);

3. Installation of new ballast water pumps, motors, controllers, associated instrumentation and control valves;

4. Installation of new ballast water piping and associated valves from pumps to main or weather deck overboard manifolds;

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[3] Although the volume of discharge should remain the same for retrofitted vessels, it will be at a higher pressure due to the change in head. It is therefore likely that the existing ballast water pumps and motors will require replacement. Existing control valves, strainers, controllers, and wiring will likely be reused.

5. Installation of any required new electrical connections for power, control and instrumentation; and

6. System testing.

As shown in Table 4.1, design engineering costs for modifying a containership or bulk carrier would be approximately $30,000, materials (pumps, piping, valves, etc.) would be approximately $190,000 and labor and services would be approximately $180,000, for a total modification cost of approximately $400,000. Tankers would generally require more piping and would therefore have higher associated costs.

Due to variability between vessels, these cost estimates are only approximate. These estimates were determined based on discussions with various marine engineers and naval architects, including R. Harkins, Lakes Carriers Association; R. McCahon, Marco Shipyard; Cascade Machinery; Pump Industries and various references (e.g., Herbert, 1999; Tagg, 1999; Mackey et al., 2000, Parson, 1998; and Oemcke, 1999).

The cost estimates are presented in Table 4.1 and are based on the following assumptions:

- Piping size, pump and pump power requirements are based on overcoming a 30-meter head at rates of 1,000 MT/hr for all three vessel types[4]. The power requirements used to size pumps were assumed to be 0.066 KW/MT/hr;

- For most ships, new shore connection handling gear would not be necessary. On tankers the shore connection would be located at the mid-ships loading/discharge manifold where it would be able to be serviced by the existing hose handling equipment (crane or boom); and on other vessels it would be located at the bunkering (fueling) station, where it could be serviced by the existing bunker hose handling gear;

- As a result of the head increase, for all three vessel types, existing ballast water pumps would need to be replaced with more powerful pumps. The tankers and bulk carriers would have the same pumping requirements;

- Containerships and bulk carriers would require approximately 55 meters of new 40-cm

[4] (Note that container vessel pumping capacity ranges from 1,000 to 2,000 MT/hr, while for tankers and bulk carriers it ranges to over 20,000 MT/hr.)

diameter piping and associated valves and manifolds running from the discharge of the ballast water pump to the main or weather deck. Tankers could require considerably more piping, although many already have the ability to pump oily ballast water ashore for treatment; and

- Labor costs would be approximately equal to material costs and engineering costs were assumed to be approximately 7% to 10% of the total modification costs.

5.0.1 System Operations Costs

The primary operational cost of the modified system would be the additional fuel required to produce the additional required electrical power. It can be assumed that before the modifications were performed, the vessels were moving the same volume of ballast water as after installation. The difference in operating costs for the vessel would be the incremental increase in fuel usage for the larger pumps and motors required to overcome the 30-meter vertical distance. In light of other expenses and costs, these differences in cost are likely to be minimal.

In addition to the increased cost of the fuel, the other large operational cost would be the increased labor time (crew costs). It would likely take at least two crew members one hour to remove the shore connection blank, rig up the shore hose, bring it on board, bolt-up to the shore connection, and begin transferring ballast. The system would also require monitoring during ballast discharging operations. The actual crew cost in dollars is difficult to quantify given the variety of countries from which vessel crews originate.

5.0.2 New Construction Costs

Providing the equivalent off-ship transfer capability in the design and construction of a new vessel would likely reduce the costs of the above by an order of magnitude. However, it should be noted that vessels are long-lived capital equipment. The vessel being delivered today can be expected to be in operation for at least ten years and active vessel lives in excess of 35 years are not uncommon.

Similarly, some types of vessels may be designed to minimize or, eliminate the need for ballast water discharge.

5.0.3 Increased Costs Due to Vessel Delays

Vessel delays could lead to increased costs to vessel operators and/or agents, including demurrage, dockage, hire or charter rates, pilotage, and shore-side labor costs. The costs vary widely between ports both nationally and internationally and are not included in the economic assessment of the onshore treatment option.

Demurrage

Demurrage is a charge levied by the vessel owner for the period a vessel is retained beyond the allocated time for unloading or loading. Typical demurrage charges in large California ports are presented below (R. Lindsay, General Steamship Corp. and John Berge, Star Shipping, *pers. comm.*).

- Panamax Container Vessel: $20,000 per day
- Afromax Tanker: $12,000 per day
- Panamax Bulker: $11,000 per day

Dockage

Average dockage rates at California Ports for all vessel types are approximately $4,400 for the first 24 hours and $850 per subsequent six-hour period or fraction thereof (G. Hallin, Port of Oakland, *pers. comm.*).

Hire or Charter Rates

Hire or Charter rates are essentially the "rent" paid by a charterer for the use of the vessel. These rates vary widely based on the vessel and contract type but figures between $8,500 to over $20,000 per day are common (R. Lindsay, General Steamship Corp., *pers. comm.*).

Other Fees

If, due to a delay, a vessel is forced to go to anchorage or shift berths, a pilot and tug fee of approximately a $1,000 could be expected (R. Lindsay, General Steamship Corp., *pers. comm.*). A cargo gang costs approximately $12,000 per eight-hour shift.

In total, a large container vessel delayed in a major California port for an extra day could generate over $70,000 in delay related costs. The cost impact on the vessel's schedule cannot be easily estimated.

3.0.1 Other Vessel Operation Considerations

It may not be possible for all vessels to discharge all ballast water to an onshore facility without seriously impacting cargo loading. Shipboard ballasting operations vary widely from ship to ship and voyage to voyage, based on the particular vessel, cargo, weather conditions, tides, and other conditions.

Ships often discharge ballast water while transiting to the wharf or while at anchor. These discharges may be for a variety of reasons, including: stability, under-keel clearance, taking on fuel or cargo while at anchor, and to reduce the time necessary at dock as cargo can sometimes be loaded faster than ballast can be discharged. The ballast water that is discharged before berthing would not be directly accessible to onshore treatment.

Vessels do not always have the ability to transfer ballast water internally while loading or unloading cargo to compensate for structural bending, trim, and list. For example, many containerships have the capability to transfer ballast water between a pair of wing tanks for heel control, but few have the capability to transfer water fore and aft to keep the ship in level trim (Herbert, 1999). As a result, vessels often must deballast some tanks while ballasting others.

3.1 WHARF RETROFITTING

The second component of the conceptual onshore ballast water treatment system is wharf retrofitting. To avoid delays during cargo handling, every wharf would have to have the capability to handle ballast water transferred ashore. To capture ballast water discharged from a vessel underway or at anchor, a mobile collection system would also be required. Such a mobile system is not addressed in this analysis.

It is possible that all active wharves within a port might not need retrofitting. Ports with high volumes of vessel traffic, with most or all vessels discharging ballast water would likely require reticulation to all wharves to avoid delays. However, ports with either very few vessel calls, or with only a small number of vessels discharging ballast water may only require a few wharves to be connected. This determination would require a detailed port-specific analysis of present and future shipping and ballast water discharge patterns and is beyond the scope of this report.

Vessel types can require wide ranges of ballast discharge flow rates for cargo handling operations. One vessel may only require a 20-centimeter overboard line, whereas another vessel may require a 40-centimeter overboard line. To accommodate this variability, the new shore discharge line will have to be sized to accommodate the greatest potential flow from a vessel. Also to maintain simplicity and ease of operation, the shore connection should be a standard size on all vessels. This is similar to existing regulations regarding International Shore Connection for fire water, and standard discharge connection size for shoreside discharge of oily waste per IMO MARPOL I/19.

For the purposes of this study it has been assumed that all ports will have 60-centimeter piping to carry ballast water from the vessels to the storage tanks. Costs for materials and basic pipeline installation are approximately $328 per meter ($100/ft). Experience indicates that including required permitting, pumps and valves, etc., approximately doubles the cost to $656/m ($656k per kilometer). This cost is consistent with the (Australian) $1.4 million figure for 1.4 km of pipeline (approximately $590k US per kilometer) estimated by ENRC (1997) to reticulate a small Australian port. It has been assumed that right-of-ways for pipelines can be obtained if necessary. Costs could be significantly higher if right-of-ways cannot be obtained or if environmental issues are involved.

As an example of actual costs to install lines at port facilities, the Port of Oakland is in the process of constructing 2.5 kilometers of 51-centimeter force main, approximately 0.4 kilometers of 76-centimeter gravity line to cross a channel and upgrading a pump station. The total cost for the project is $9.2 million (excluding some project management costs) of which $2.2 million is for the pump station upgrade. The remaining $7.0 million is the cost to install 2.9 kilometers of pipeline (T. Mankowski, *pers. comm.*). The costs include design, planning and construction in addition to environmental documentation, and permitting. Most of the right-of-way was obtained at no cost, which may not always be the case.

3.1.1 Requirements for California Ports

Information on the piping lengths required to retrofit the wharves at each CAPA port is discussed below and summarized in Table 4.2. Costs associated with the piping are presented in Section 5.2. The discussion includes specific issues related to each port.

Port of Hueneme

The Port of Hueneme includes two terminals. The South Terminal is a continuous 550-meter wharf with three 180-meter berths. North Terminal is a 440-meter wharf with two 213-meter deep draft berths. To pipe the terminals to a centralized facility would require approximately 1.6 kilometers of pipeline. The Port includes 95 acres (0.38 km^2), but there is no space available for a storage or treatment facility (P. Wallace, Director of Operations, *pers. comm.*).

Port of Humboldt Bay

The Port of Humboldt Bay consists of eight terminals (10 berths), located in three different areas of the Bay; Eureka, ocean-side, and south bay. Connecting all of the terminals would involve over 19.3 kilometers of piping (D. Hull, *pers. comm.)* and would require a pipeline beneath the Bay.

Constructing a pipeline beneath the Bay would be complicated by a myriad of environmental issues and may not be feasible. The alternative would be to build three separate treatment facilities for the three terminal areas. Land is available at the Port.

Port of Long Beach

The Port of Long Beach includes approximately 64 operational berths and would require 43.6 kilometers of pipeline to connect the wharves to a single treatment facility (R. Riffenburg, Deputy Chief Harbor Engineer, *pers. comm*.). There is some land available at the Port.

Port of Los Angeles

The Port of Los Angeles has a total of 71 operational berths (D. Rice, Director of Environmental Management, *pers. comm*.). The wharves are spread along several branching channels. Assuming a centrally-located treatment facility, connecting all of the wharves to the facility would require a minimum of 27 kilometers of pipelines and 7 channel crossings. Channel crossings are possible but very expensive. Avoiding placing pipelines under channels would require approximately 41.2 kilometers of pipelines for a single centrally-located treatment facility and approximately 36.2 kilometers for two facilities located on different sides of the Port. Land for a treatment/storage facility could likely be made available.

Port of Oakland

The Port of Oakland has 28 deepwater berths at nine container terminals and two breakbulk cargo terminals. Over 24.1 kilometers of piping would be required to connect the wharves to a centralized facility. All vacant Port land is planned for future Port development. An onshore facility would displace other proposed uses (R. Boyle, *pers. comm*.)

Port of Redwood City

The Port of Redwood City has five wharves. Two wharves are 274 meters long, two are 229 meters long, and one is 152 meters long. Connecting the wharves to a central facility would require approximately 2.4 kilometers of piping (S. Khoo, Port Operations Manager, *pers. comm.*). Due to the proximity of Silicon Valley, land costs are at a premium, which may limit economic feasibility of storage.

Port of Richmond

The Port of Richmond has four wharves, several miles apart (J. Matzorkis, *pers. comm.*). The distance for piping between the terminals is approximately 8.9 kilometers. There is no land available at the Port for a treatment facility.

Port of Sacramento

The Port of Sacramento includes five 183-meter berths. The wharves are on both sides of the Sacramento River. There is land available for the treatment system and/or storage tanks about 550 meters from two of the berths and 610 meters from the other three berths (T. Scheller, Port Engineer, *pers. comm.*). The total piping required would be approximately 2.1 kilometers. Port pipelines to a central facility would require piping under the River. Otherwise, two treatment systems would be required. It is unknown whether discharge of treated saline ballast water would be permitted under NPDES to the fresh water port.

Port of San Diego

The Port of San Diego consists of three terminal areas. Cargo is handled at the 10th Avenue Marine terminal (8 berths) and the National City Marine Terminal (6 berths). Cruise ship and passenger services are at the B Street Pier and Broadway Pier (5 berths each). It would require about 14.2 kilometers of pipeline to connect the three areas to a central facility (D. Winchip, Chief Wharfinger, *pers. comm.*). Land is available at the Port.

Port of San Francisco

The Port of San Francisco includes two terminal areas approximately ten kilometers apart. There are two deep-draft container terminals with six berths, two berths for cruise ships, two lay berths for Navy vessels, two dry docks with three lay berths, and six berths for MARAD vessels (J. Davey, Marine Operations Manager, *pers. comm.*). The container terminals are 750 and 825 meters long. Connecting the terminals to a central facility would require approximately 12.9 kilometers of piping. To connect the terminal areas to a treatment facility would involve laying a pipeline beneath the Embarcadero, for which obtaining a right-of-way is likely not an option. No land is available in the Port and a parcel would have to be purchased from a private party at a price of approximately $7,500/m^2.

Port of Stockton

The Port of Stockton will have 23 180-meter berths when 10 berths at the Naval Base become operational. Connecting the wharves would require approximately 8.2 kilometers of total piping. The system would require either a pipeline under the San Joaquin River, or two treatment and storage systems (L. Hieber, Deputy Port Director, *pers. comm.*). It is unclear whether discharge of treated saline ballast water would be permitted under NPDES to the fresh water port.

3.2 BALLAST WATER STORAGE TANKS

The third component of the conceptual onshore system is the ballast water storage tanks. This treatment scenario assumes that each port would require ballast water storage capacity equal to two days' volume of maximum discharge. This capacity would be needed to: 1) minimize the required capacity of the treatment system; 2) equalize peak surge flows from deballasting vessels to allow the treatment facilities to operate at constant average rates; 3) allow vessels to discharge ballast water at rates higher than those of the treatment system; 4) allow for times when ports receive greater than the average number of vessel calls per day; 5) allow for vessels discharging greater than average volumes; and 6) allow for maintenance on the treatment system and for storage in the event that the treatment system breaks down.

To determine the required storage capacity and the capacity of the treatment facility that would be required by each port, available port-specific data on vessel calls and ballast water discharge were gathered and analyzed. Data sources included individual port records, data collected by the California State Lands Commission (SLC), and USCG (through SERC) Data. It is important to note that the reported volumes discharged may significantly under-represent the actual volume of discharge in some ports. All of the databases used to estimate discharge for this study include only vessels arriving from outside of the U.S.

EEZ (see Figure 1.1) and therefore do not include discharges of ballast water from coastal traffic. These discharges may be significant.

In addition, some vessels are not currently submitting ballast water report forms and therefore, their discharge is not included. Of the total numbers of vessels calling on various California public ports, between 42% and 93% submitted ballast water reporting forms (Appendix A). The reporting levels are expected to improve as more operators become familiar with the reporting requirements. Despite these omissions, the data are currently the best information available. Designing and sizing an actual facility would require a much more extensive investigation of port usage and actual ballast water discharge.

Available information on vessel arrivals and ballast water discharge for California ports is presented in Appendix A and summarized in Table 4.3. Between California Ports there is a large range in the frequency of vessel calls and volumes discharged. In addition, not all vessels discharge ballast water in port. Some ports, such as Los Angeles, regularly receive several vessel calls per day, of which, several calls per week discharge ballast water. Other ports, such as Hueneme, may only receive one vessel call or less per month. Average daily discharge volumes (total volume reported divided by the number of days covered) range from over 3,700 MT at the Port of Los Angeles to 2 MT at the Port of Hueneme. It is assumed for these calculations that the discharge volumes in this data are representative of normal port operations.

Although average discharge volumes per day were calculated for each port to determine required capacity for treatment (Table 4.5), the dockside reticulation and storage system must be able to accommodate the maximum volume per day for each port. The average and maximum volumes are often significantly different. For example, the Port of Los Angeles has an average daily discharge volume of 3,761 MT and a maximum daily volume of 76,789 MT. Required storage would be approximately 41 million gallons, but the treatment system would only need a capacity of about one million gallons per day (3,785 MT/day).

All storage tanks are assumed to be epoxy-coated welded-steel built on slab foundations. The costs to design and construct tanks under seismic or difficult soil conditions have not been included in the analysis.

3.2.1 Discharge Data for California Ports

The following section presents the port-specific ballast water discharge information used to size the storage and treatment facilities. Information on ballast water discharge in most California ports is available from the Smithsonian Environmental Research Center (SERC) for July through December 1999 and from the State Lands Commission (SLC) for January through March 2000. The available data for each port are summarized in Table 4.3. As noted above, the volumes reported in Table 4.3 likely under-represent the actual volumes of ballast water discharged in port as some of the available databases include only vessels arriving from outside the U.S. EEZ and only those vessels that correctly completed ballast water survey forms. Some ports may receive significant amounts of ballast water that was taken on from within the U.S. EEZ, but most reporting forms do not record this information.

Port of Hueneme

The Port of Hueneme receives approximately 365 deep draft vessel calls per year, mostly from overseas. The vessel types include reefers, bulk carriers, car carriers, and roll-on roll-off (ro-ro) vessels. Most vessels calling at the Port do not discharge ballast water in port. Available data for July 1999 through March 2000 indicate only five vessels discharged a total volume of 517 MT of ballast water.

Port of Humboldt Bay

Humboldt Bay receives approximately 60 deep draft vessel calls per year (D. Hull, *pers. comm*.). These include 40,000 DWT woodchip carriers that arrive in ballast, and discharge an average of 12,000 MT of ballast water. Ballast water discharge data for July through December 1999 indicate a total volume of approximately 98,000 MT was discharged during this period. The average volume discharged per day was 530 MT and the maximum discharge volume recorded for a single day was 14,930 MT.

Port of Long Beach

The Port of Long Beach is the largest container port in the United States. The Ports of Long Beach and Los Angeles constitute the third largest container port complex in the world. The Port of Long Beach primarily receives container vessels but also receives bulk carriers, tankers, reefers, ro-ros, car carriers, and general cargo vessels.

Available data for the second half of 1999 indicate the total volume of ballast water discharged in the Port was approximately 480,000 MT. The average volume discharged per day was 2,573 MT and the maximum volume recorded for a single day was 19,324 MT.

Port of Los Angeles

The Port of Los Angeles is the second largest container port in the United States. The Port of Los Angeles receives primarily container vessels, but also receives reefers, bulk carriers, tankers, ro-ros, and general cargo vessels.

Based on available data for July through December 1999, the total volume of ballast water discharged in the Port of Los Angeles was approximately 700,000 MT. The average volume discharged per day was 3,761 MT and the maximum recorded volume discharged in a single day was 76,789 MT. The maximum one-day discharge volume was the result of two coal carriers and one container vessel discharging ballast water. Each of the coal carriers discharged 37,900 MT whereas the container vessel discharged just under 1,000 MT.

Port of Oakland

The Port of Oakland receives primarily container vessels, but breakbulk carriers and general cargo vessels also call on the Port. Information on ballast water discharged in the Port is available from the SERC database for the second half of 1999 and from the State Lands data for the first quarter of 2000. These databases generally include only discharge data from vessels arriving from outside the U.S. EEZ. The Port of Oakland collected data for vessels arriving from October through December 1999 that discharged ballast water in port originating from within the U.S. EEZ. These volumes were added to the SERC data for the same period.

Based on the available data, the Port of Oakland received approximately 166,000 MT from July 1999 through March 2000. The average volume discharged per day was 605 MT and the maximum recorded discharge for a single day was 13,883 MT.

Port of Redwood City

The Port of Redwood City receives primarily bulk carriers transporting construction materials such as bulk cement, sand and aggregates. Available data for the second half of 1999 show that during this period a total volume of approximately 39,000 MT of ballast water was discharged in the Port. The average volume discharged per day was 214 MT and the maximum recorded for a single day was 15,829 MT.

Port of Richmond

The Port of Richmond primarily receives vessel calls from bulk carriers and oil and chemical tankers. Most vessels calling at Richmond take on ballast water at the Port. Information on ballast water discharge in the Port of Richmond is available for July 1999 through March 2000. A total volume of approximately 46,000 MT of ballast water was discharged in the Port during this period. The average volume discharged per day was 168 MT and the maximum recorded volume discharged in a single day was 12,540 MT.

Port of Sacramento

The Port of Sacramento primarily receives bulk carriers and wood-chip carriers. Information on ballast water discharge in the Port is available for July 1999 through March 2000. During this period, a volume of approximately 103,000 MT of ballast water was discharged in the Port. The average volume discharged per day was 376 MT and the maximum recorded volume for a single day was 17,836 MT.

Port of San Diego

The Port of San Diego receives calls from bulk carriers, car carriers, general cargo vessels, reefers, tankers, and ro-ros. Based on the available data, from July 1999 to March 2000, approximately 59,000 MT of ballast water was discharged in the Port of San Diego during this period. The average daily discharge volume was 216 MT and the maximum recorded discharge volume for one day was 11,419 MT.

Port of San Francisco

The Port of San Francisco receives primarily oil and chemical tankers and containerships, but also receives general cargo vessels, bulk carriers, and ro-ros. The maximum recorded discharge volume for a single day was from two oil tankers.

Data on ballast water discharge are available for the Port of San Francisco from July 1999 through March 2000. During this period, a volume of approximately 114,000 MT of ballast water was discharged in the Port. An average volume of 314 MT was discharged per day and a maximum recorded volume discharged in a single day was 23,477 MT.

Port of Stockton

The Port of Stockton receives primarily bulk carriers. Information on ballast water discharge in the Port is available for the second half of 1999 and for the first quarter of 2000. During this period, a total reported volume of approximately 53,000 MT of ballast water was discharged in port. The average volume discharged per day was 192 MT and the maximum recorded volume for a single day was 20,705 MT.

3.2.2 Requirements for California Ports

Based on the recorded discharged ballast water volumes presented above, the required storage capacity that would be required for each port was calculated using the following assumptions:

- The available discharge volumes are representative of normal port operations;

- All vessels accurately report discharge. (See Section 4.3);

- All ports would utilize 7.3-meter (24-foot) tall above-ground epoxy-coated steel storage tanks;

- Each port would require storage capacity equal to two-days' worth of maximum discharge; and

- This storage would adequately provide for above-average discharge and periods when maintenance and/or repair of the treatment system would be required.

Table 4.4 presents the calculated storage facility capacities, tank dimensions and cost estimates for California ports. Land costs were not included. No growth factor for future capacity requirements was applied. Section 4.4 presents the conceptual design of the treatment facility module.

As shown in Table 4.4, calculated tank dimensions range from eight 58-meter diameter tanks required for the Port of Los Angeles (requiring approximately 21,000 m^2) to a single 8.5-meter diameter tank for the Port of Hueneme (requiring 57 m^2). The largest tanks required, for the Port of Los Angeles are estimated to cost approximately $20.4 million, while the smallest tank, for the Port of Hueneme would cost approximately $55,000.

The construction costs estimated in Table 4.4 do not include costs for permitting or seismic calculations that may be required for the foundations. If seismic evaluation is required, costs could be significantly higher.

5.1 ONSHORE TREATMENT FACILITY CONCEPTUAL DESIGN

This section describes the conceptual onshore ballast water treatment facilities that comprise the fourth component of the conceptual onshore facility. Design criteria are presented in Table 4.6 for each of the California ports. A schematic of the treatment process is presented as Figure 4.5 and a site schematic is presented as Figure 4.6.

The conceptual design of the onshore ballast water treatment facility includes treatment by filtration followed by UV irradiation. This combination of existing technologies was chosen based on their proven performance in potable and wastewater treatment, and their worldwide availability. For onshore treatment to be a feasible option, it must be effective and it must be possible to implement treatment at all port locations and in countries with differing levels of economic development. Proven and robust technology is needed to meet this requirement. Alternative technologies including the hydrocyclone technology being implemented for shipboard applications or advanced membrane filtration may be applicable for removal of invasive species. However, questions regarding the effectiveness, reliability, cost, and worldwide availability of such technologies have not yet been answered. For example, hydrocyclone technology relies on the difference between the specific gravity of seawater and that of the organism to cause separation and hence filtration. Yet many coastal species are neutrally buoyant (they have the same specific gravity as seawater) and may not be removable by hydrocyclone. The results of ongoing studies (Fisheries and Oceans Canada, Hyde Marine/P/V Regal Princess) are needed to demonstrate the effectiveness of hydrocyclones.

Filtration technology removes particles and organisms down to 50 microns. The filtered water then passes through a bank of UV lamps, which provide a dose of UV irradiation sufficient to kill or inactivate the remaining organisms. The solids/sludge filtered out of the water prior to UV treatment would be thickened either by dissolved air flotation (DAF) or inclined plate thickening and then dewatered via a plate and frame press.

The treatment facility design is based on the assumptions that the facility would be required to treat the average discharge volume per day for each port. Because the storage facility would have the capacity to handle the maximum discharge of ballast water per day, ballast water could be discharged from vessels at significantly faster rates than it is treated.

5.1.1 System Elements

The following sections describe the various elements of the treatment system.

Filtration System

Solids must be removed prior to UV treatment since UV is much less effective when particles shelter or mask organisms. Ballast water would be pumped from the storage tanks to the treatment system at a constant rate through the filtration system. The filters remove solids greater than 50 microns. A continuous backwash filtration process is proposed for two reasons:

1. The continuous backwash filtration process is based on existing technology widely used for secondary effluent prior to disinfection at many wastewater treatment facilities. It was

assumed that ballast water at these facilities would be disinfected to the same standard.

2. The continuous backwash process results in a steady flow of filtered water and reject (backwash) water to downstream processes. As a result, the need for filtered-water and backwash storage tanks is eliminated.

It should be noted that backwash and membrane filtration systems remove particles and organisms independent of the specific gravity of the organisms. As mentioned above, hydrocyclone and hydrocyclone filtration systems use the difference in specific gravity between an organism and seawater to achieve separation. In theory, a neutrally buoyant organism could pass through a hydrocyclone. However, protection against such organisms surviving is provided by the UV disinfection phase.

Various chemicals would be added to the treatment stream at the filters. These include chlorine for control of algae and slimes, a coagulant such as alum or ferric chloride, and a polymer flocculent to aid in filtration. As with existing wastewater treatment systems, these chemicals would be either neutralized or removed before discharge. Experience with filtration of wastewater secondary effluent has indicated that flocculation basins have a minimal effect prior to filtration, and as such, are not proposed for this system.

Ultraviolet Disinfection

After filtration, the effluent would flow through a UV disinfection channel. UV irradiation is effective for treatment of fresh water and has the potential to treat saline water for a wide range of organisms (Oemcke, 1999). Disinfection or inactivation of organisms occurs as organisms flow by the UV lamps mounted in a channel. The UV light damages the cells of organisms so that they die or are unable to replicate.

The degree of disinfection is dependent on the type of organism and the dose (light intensity and exposure time). UV dose is expressed in milliwatts (mW) multiplied by exposure time in seconds per square centimeter (mWs/cm^2). In fresh water, the effective dosage for most organisms is on the order of 10 to 25 mWs/cm^2 (to achieve 99.99% inactivity) although higher doses on the order of 100 mWs/cm^2 are necessary to inactivate some cyanobacteria and protozoa (Levine & Thiel, 1987; Campbell et al. 1995). Fewer studies have been performed on the dosages of UV required to treat the wide range of marine biota found in ballast water. Ongoing research by Fisheries and Oceans Canada is investigating the dose response behavior for a number of marine organisms found in ballast water including shrimp, mussel and clam larvae, diatoms and dinoflagellates (T. Sutherland, *pers. comm.*). Sugita et al, (1992) found dosages less than 25 mWs/cm^2 were effective for treatment of bacteria in salt water. Higher dosages (greater than 200 mWs/cm^2) may be required to inactivate some organisms such as viruses (Chang et al, 1998).

At the present time, a UV dosage standard for the treatment of ballast water has not been established. However, a treatment standard must be assumed in order to design and cost the treatment facility. In lieu of ballast water standards, wastewater quality standards were evaluated. Standard secondary wastewater treatment systems are designed to deliver doses of 25 mWs/cm^2. The California Wastewater Reclamation criteria (Title 22, California Code of Regulations) specify more stringent standards for the most restrictive reuse of wastewater. In situations where skin contact with wastewater may occur, a minimum UV design dose of 140 mWs/cm^2 is specified (National Water Research Institute, 1993).

Previous marine and ongoing studies tend to indicate that the UV dosages required to inactivate the full range of biota sizes and life stages found in ballast water will be higher than those used for fresh water. Hence the 140 mWs/cm^2 treatment standard was assumed for design purposes in this study. This standards is in the same range as the 130 mWs/cm^2 dosage applied in the design of the onboard ballast water treatment system installed in the P/V *Regal Princess* (T. Mackey, *pers. comm.*).

Residual Thickening

Backwash sludge (solids and colloids removed from the ballast water during filtration) contains a high percentage of water, much of which must be removed prior to disposal at a landfill facility. This sludge would be thickened and then dewatered. Two types of thickening would be utilized for the various facilities. Dissolved air flotation (DAF) would be applied at the larger facilities based on the large volume of reject flow. In the DAF process, the reject flow is pressurized and compressed air is dissolved into solution. When the pressure is lessened, fine bubbles form in the liquid and attach to sludge particles, causing the particles to float to the surface. These particles could then be removed. DAF thickens the material to 3% solids or greater.

For facilities with lower capacities, inclined plate clarifiers would be used. These provide gravity settling for the sludge in a zone without currents or turbulence. The solids accumulate at the bottom of the clarifier and could be removed. This process results in solids concentrations of approximately 1%. During both of these processes, polymers would be added to enhance settling and thickening.

Residual Dewatering

After the sludge has been thickened by one of the processes above, the residual would be dewatered though the use of a plate and frame filter press. The sludge would first be conditioned in a batch conditioning tank with polymers, causing the sludge to further coagulate and release unbound water. The conditioned solids would be pumped under high pressure in between multiple plates in the press. Between each set of plates a "void" lined with filter fabric would allow water to flow out, but retain the solids. After pumping, the plates would be taken apart and the remaining solids taken to a landfill facility.

2.0.1 Requirements for California Ports

Conceptual onshore ballast water treatment facilities were designed for four different treatment capacities based on the ballast water discharge data presented in Table 4.5. The capacities considered were 1.0 mgd (3,785 MT/day) each for the Ports of Los Angeles and Long Beach, 0.2 mgd (757 MT/day) for the Ports of Humboldt Bay, Oakland, and San Francisco, 0.1 mgd (379 MT/day) for the Ports of Redwood City, Richmond, Sacramento, San Diego, and Stockton, and 0.001 mgd (4 MT/day) for the Port of Hueneme. Facility design specifications for each port are included in Table 4.6.

Each of these facilities would have similar processes, with a few differences. The facilities are described below.

1.0 MGD Facility (Los Angeles & Long Beach)

Ballast water treatment facilities with capacities of 1.0 mgd would be adequate for the Ports of Los Angeles and Long Beach. The 1.0 mgd facilities would include initial filtration of ballast water to 50 microns, followed by UV treatment, DAF thickening, and dewatering. The filters, such as Parkson Dynasand or equivalent, are continuous backwash filters, which maintain a constant flow through the facility. A backwash surge tank should not be necessary.

A DAF thickener as described above would be used due to the quantity of sludge and to minimize the required pumping and handling capacity during dewatering of the filter residue. Dewatering would be performed with a plate and frame press.

0.2 MGD (Humboldt Bay, Oakland, and San Francisco) & 0.1 MGD (Redwood City, Richmond, Sacramento, San Diego, and Stockton) Facilities

The 0.2 and 0.1 mgd ballast water treatment facilities would provide adequate capacity for the Ports of Humboldt Bay, Oakland, and San Francisco (0.2 mgd) and the Ports of Redwood City, Richmond, Sacramento, San Diego, and Stockton (0.1 mgd). These facilities would include initial filtration, followed by UV treatment, inclined plate thickening, and dewatering.

The filters are continuous backwash filters as for the 1.0 mgd facility. The thickeners, however, could be inclined plate thickeners, such as Parkson Lamella or the equivalent. These would thicken to 1%, while DAF could be expected to be 3% or better. This difference is acceptable for the smaller quantities of sludge produced at the smaller capacity plants. Dewatering would be accomplished with a plate and frame press as in the 1.0 mgd facility.

0.001 MGD Facility (Port of Hueneme)

The Port of Hueneme would require treatment of approximately 0.001 mgd of ballast water. The facility could be the same design as the 0.01 mgd facility. However, treatment of such a small volume of ballast water is not economically feasible and the volume could likely be discharged to the city sewer system, reballasted to an outgoing ship, transported by a separate vessel for discharge at sea, or transported to Los Angeles or Long Beach for treatment.

If treatment were required, a 1,200 gallon storage tank, a cartridge or bag filter, and a 1,000 gallon batch tank for chlorine disinfection followed by sodium bisulfite could be used.

2.0.2 Capital Costs

Capital costs associated with construction of the onshore treatment facilities include those for paving and grading the sites, construction of the facility buildings, treatment tanks, filters and pumps, thickeners, and electrical and instrumentation equipment. The cost of land for the treatment facilities and storage tanks costs of environmental studies and permitting are not included in this analysis. Estimated capital costs for the treatment facilities for each port are presented in Table 4.7.

Estimated capital costs for onshore treatment facilities (excluding costs for port piping and storage tanks) at specific California ports range from approximately $1.6 million each for the 0.1 mgd facilities for the Ports of Redwood City, Richmond, Sacramento, San Diego, and Stockton, to over $2.2 million each for the 1.0 mgd facilities for each of the Ports of Los Angeles and Long Beach. As described in Section 4.4.2, a treatment facility was not designed for the Port of Hueneme due to the very small volumes of ballast water involved. Capital costs for the remaining ports are in the range of $1.8 million.

2.0.3 Operations & Maintenance Costs

Annual operating and maintenance costs are estimated in Table 4.8 for each port. The costs include chemicals, electricity, labor (facility operators), laboratory costs, and landfill disposal costs (minimal). Estimated annual costs for California ports range from $142,000 to $223,000.

2.1 OUTFALL AND SOLIDS DISPOSAL

The final component of the conceptual onshore system is the outfall, through which treated ballast water would be discharged back to port waters. It is assumed that the treated water would be considered benign and an NPDES permit for discharge could be obtained from the appropriate Regional Water Quality Control Board. Development of disinfected ballast water standards defining mortality or removal percentage would be necessary to demonstrate to a Regional Board that the treated water is benign. The Regional Boards would also need to find that the discharges are consistent with the Regional Water Quality Control Plans (Basin Plans) and Ocean Plans.

It is unknown whether fresh water ports such as Sacramento and Stockton would be able to discharge treated ballast water directly to the Sacramento or San Joaquin Rivers because of the high salinity of the water. Alternative, and likely more costly, disposal techniques such as transporting the water back to saline waters would need to be considered.

Based on POTW experience, a simple channel outfall or pinch-valve pipe outfall could be designed, permitted, and constructed for approximately $100,000. This estimate assumes no additional environmental permitting or mitigation are required.

As described in Section 4.4, it is assumed that the small volume of solids resulting from filtration at the onshore treatment plant would not be hazardous and could be disposed of at a Class III landfill. Disposal costs for benign waste at such facilities are approximately $20/ton.

1.03DISCUSSION

The following section presents a discussion of the issues related to general conceptual feasibility of onshore ballast water treatment from technical, operational, and economic perspectives. The feasibility of installing onshore systems at specific California ports is then evaluated.

3.1 CONCEPTUAL FEASIBILITY OF ONSHORE TREATMENT

The concept of onshore treatment of ballast water is evaluated based on three aspects; technical feasibility, operational feasibility, and the cost of onshore treatment.

3.1.1 Technical Feasibility

The technical feasibility assessment is based on the criterion of whether onshore treatment of the ballast water currently discharged at California ports is technically possible using existing technology, irrespective of operational and cost considerations.

Onshore treatment of ballast water is technically feasible, provided the technology to achieve current wastewater treatment standards is equivalent to the technology required to treat ballast water for invasive species. It is technically possible to retrofit most vessels to allow for discharge to an onshore facility. It is possible to retrofit most wharves with connections and piping to transport ballast water to a treatment facility. Storage tanks could be built to accommodate the maximum discharges of ballast water from vessels and would allow for a reduced treatment capacity. Ballast water could be treated at onshore facilities using a combination of filtration and UV irradiation to remove or kill invasive species. With the possible exception of fresh water ports, treated ballast water could be discharged back to port or nearshore waters through an NPDES permitted outfall and the resulting solids disposed of at a landfill facility.

The scenario presented assumes that existing wastewater treatment technology is sufficient to meet the requirements of future ballast water standards. If ballast water standards follow the typical pattern of gradual tightening of standards as knowledge and technology improve, this assumption seems reasonable.

Other ballast water management technologies under investigation include shipboard treatment using filtration and UV, ozone treatment, development of potent biocides with short half-lives and improved design of ballast water tanks. With many technologies under development and consideration at this time, it is not yet possible to determine which technology will be the preferred management tool.

3.1.2 Operational Feasibility

The operational feasibility assessment is based on the criterion of whether all ballast water presently discharged within the U.S. EEZ could be discharged to onshore treatment facilities without causing significant delays to vessel operations or compromising vessel safety.

Vessel Retrofitting

After vessel retrofitting, it would be possible for containerships to discharge the ballast water associated with cargo loading at the wharf. The operational feasibility of wharf-side discharge for bulk carriers and tankers is less certain because the discharge volumes and rates required during cargo loading operations are much higher for these types of vessels. In addition, many bulk carriers discharge ballast water on approach to the wharf to enable faster cargo loading. Constraining these vessels to onshore discharge could potentially significantly impact vessel schedules.

Vessels also often discharge ballast water when approaching ports to reduce draft for adequate hull clearance. A mechanism to transfer such ballast water to an intermediate vessel would be needed to prevent discharge to nearshore waters. Such required transfer could cause operational delays and could be subject to safety constraints. At-sea transfer of ballast water during rough weather would not be feasible.

Wharf Retrofitting

Any onshore treatment option must be capable of handling high flow rates such that offloading of ballast water does not unduly interfere with normal shipping operations. In addition, all ports must have standardized connections sized to handle the highest potential flows. Based on the experience of discharge of non-segregated ballast water from oil tankers, the wharf-related component would be operationally feasible once a common shore connection standard was established, the wharf-side collection system was in place and crews were trained.

Storage & Treatment Facilities

Operation and maintenance of ballast water storage tanks and treatment facilities would be operationally feasible assuming the necessary facility operators could be hired.

Outfall/Solid Disposal

Operation of a seawater outfall would be limited to locations where such outfalls could be permitted and constructed. In locations where outfalls of salt water could not be permitted because of NPDES constraints (such as fresh water ports or water bodies with specific water quality limitations), other means to dispose of treated ballast water would need to be considered. Discharge of treated ballast water back to the sea would be the operationally most straight-forward option.

3.1.3 Onshore Treatment Costs

The cost estimates for the onshore treatment systems are comprised of five components: vessel retrofitting, wharf retrofitting, storage tanks, treatment system (construction plus annual operation and maintenance), and waste disposal/discharge. The component costs other than those for vessel retrofitting can be added and converted to a cost estimate of treatment cost per metric ton of discharged ballast water.

Costs to retrofit containerships are estimated to be approximately $400,000 per vessel. Costs to retrofit bulk carriers and tankers are expected to be higher, and due to the extreme variability in ship design, the retrofitting costs are expected to range widely. Existing vessels are likely to need some retrofitting irrespective of which ballast water management tool or treatment technology is eventually adopted.

The costs of for the four onshore treatment system components were grouped together and converted to an estimated dollar value per metric ton (MT) of treated water. For California ports, these costs range from approximately $1.40 per MT to $8.30 per MT. Vessel retrofit costs and vessels delay costs are not included in these figures. Land costs are also not included in the analysis due to the large variability in land value.

How does the $1.40 per MT to $8.30 per MT cost range compare to other potential treatment options? While there is a paucity of actual data for other treatment options, the treatment cost per ton can be compared against the costs for open-ocean exchange. The cost of the flow-through dilution method of open water exchange is $0.03 to $0.11 per MT and the full-tank reballasting (empty and fill) method is $0.02 to $0.04 per MT (Dames & Moore, 1999; Oemcke, 1999).

Whether wharf retrofitting is economically feasible is a challenging question. Installation of piping and other infrastructure have other attendant challenges. For example, 24-inch diameter piping for wharf piping has been assumed in this study. Larger diameter pipe would be required for bulk carriers and tankers if significant delays are to be avoided. There are likely to be considerable environmental issues associated with channel crossings where dredging is required or where environmentally sensitive habitat, such as wetlands, must be protected. For several ports, multiple treatment facilities may be necessary to avoid such channel crossings which would result in higher facility and operation and maintenance costs.

The required storage volumes calculated in the study likely under-represent the actual volumes required as most of the available discharge records include only vessels arriving immediately from outside the U.S. EEZ and only those vessels that correctly completed ballast water survey forms. The costs estimated for storage tanks are therefore likely to be the minimum potential costs. There will be seismic and foundation constraints on storage tanks for some ports that could significantly increase tank costs.

One of the outstanding issues in the ballast water arena is the absence of treatment standards. Standards, in effect, create the technology to meet those standards. At this time, the effectiveness of UV radiation on the diversity of taxa found in ballast tanks is uncertain. Further testing such as that being performed in the Great Lakes and Canada is needed to determine the UV dose required for effective ballast water disinfection. The cost estimates in this study developed are based on a dose of 140 mWs/cm^2. Disinfection of ballast water using much higher dosages would result in significantly increased capital, operation and maintenance costs.

Worldwide Application

A key consideration in the feasibility of any ballast water treatment option is the viability of applying the system on a nationwide or worldwide basis. Implementation of unilateral policies on a port or statewide basis would create, in the IMO's words, unfair competition between port states. For example, if only California ports required onshore treatment, there might be an economic incentive for some shipping lines to move operations to other ports or countries. Ballast water treatment requirements should be the same worldwide in order to keep a "level playing field."

3.2 FEASIBILITY FOR INDIVIDUAL CALIFORNIA PUBLIC PORTS

The technical and operational feasibility, and costs of onshore treatment were evaluated for 11 California public ports. Unless specified otherwise, the onshore treatment of ballast water at the individual ports is technically feasible. As noted in Section 5.1.1 the technology exists for all of the required components of onshore treatment.

A limitation on operational feasibility applies to those ports that receive bulk carriers. Many bulk vessels begin deballasting before coming to the wharf to allow for faster cargo loading. This ballast water would not be directly available for onshore treatment.

3.2.1 Port of Hueneme

Operational Feasibility

Operationally, onshore ballast water treatment would be feasible at the Port of Hueneme for vessels retrofitted to allow for discharge to an onshore facility. At present, most vessels calling on the Port reportedly do not discharge ballast water. All components of onshore treatment would be operationally feasible for the Port. Wharves could be retrofitted and storage tanks, a treatment facility, and an outfall could be constructed, although there is no land available at the Port for a facility.

Estimated Costs

Retrofitting the wharves at the Port of Hueneme would require approximately 1.6 kilometers of pipeline at an estimated cost of $1.06 million. Required storage could be provided by a 7.3-meter tall storage tank, 8.5 meters in diameter, at a cost of approximately $55,000.

As discussed in Section 4.4.2, onshore filtration and UV treatment for such a small volume of ballast water would not be economically feasible. The approximately 1,000 gpd could potentially be discharged to the sewer, reballasted to an outgoing ship, taken to another port for treatment, or transported by a separate vessel for discharge at sea. If treatment were required in Port, a system using a storage tank, a cartridge or bag filter, and a 1,000-gallon batch tank for chlorine disinfection followed by sodium bisulfite would be sufficient.

3.2.2 Humboldt Bay

Operational Feasibility

Operationally, onshore ballast water treatment would be feasible for the Port of Humboldt Bay if vessels were retrofitted to allow for discharge to an onshore facility. However, the Port of Humboldt Bay receives mostly woodchip carriers and other bulk carriers arriving in ballast. It may not be possible for these vessels to transfer ballast water ashore at rates required for cargo loading without causing delays. In addition, many such vessels begin deballasting before coming to the wharf to allow for faster cargo loading. This ballast water would not be directly available for onshore treatment.

The other components of onshore treatment would be operationally feasible for the Port. Wharves could be retrofitted and storage tanks, a treatment facility, and outfall could be constructed. As indicated in the following, however, the Port would require multiple treatment facilities to avoid a pipeline under the Bay.

Estimated Costs

The total capital costs for onshore treatment at the Port of Humboldt Bay are estimated at $18.6 million as shown in Table 5.1. Total annual operation and maintenance costs are estimated at $150,000. The estimated capital costs for the onshore treatment components are discussed below and summarized in Table 5.1.

Connecting the three terminal areas at the Port would involve over 19.3 kilometers of piping at a cost of approximately $12.7 million. Port reticulation would require three separate treatment facilities or a pipeline beneath the Bay. Constructing a pipeline beneath the Bay would be complicated by environmental issues and would not be economically or operationally feasible.

The Port of Humboldt Bay would require a total storage capacity of 7.9 million gallons that could be provided by two 7.3-meter tall, 51-meter diameter, steel tanks. The tanks would cost approximately $4 million. The total land area required for the two tanks would be 4,127 m^2 (1.2 acres).

The required treatment capacity for the Port is 0.2 million gallons per day. Capital costs for such a facility are estimated at approximately $1.8 million and annual operating costs would be approximately $150,000. A basic outfall structure would cost approximately $100,000 assuming there are no permitting or environmental issues.

The cost of onshore treatment at Humboldt Bay is estimated to be $3.97/MT as shown in Table 5.2.

3.2.3 Port of Long Beach

Operational Feasibility

Onshore ballast water treatment would be operationally feasible for the Port of Long Beach if all vessels were retrofitted to allow for discharge to an onshore facility. Long Beach receives a large number of container vessels. Ballast water from these vessels likely could be discharged to a wharf without causing vessel delays.

The Port also receives bulk carriers and tankers, and it may not be possible for these vessels to transfer ballast water ashore at rates required for vessel loading without causing delays. The other components of onshore treatment would be operationally feasible for the Port. Wharves could be retrofitted and storage tanks, a treatment facility, and outfall could be constructed.

Estimated Costs

The total capital costs for onshore treatment at the Port are estimated at $36 million as shown in Table 5.1. Total annual operation and maintenance costs are estimated at $223,000. The estimated capital costs for the onshore treatment components are discussed below and summarized in Table 5.1.

The Port of Long Beach would require 43.6 kilometers of pipeline to connect its wharves to a treatment facility at an estimated cost of $28.6 million. The Port would require a total storage capacity of 10.2 million gallons. Two 7.3-meter tall, 59-meter diameter, steel tanks would cost approximately $5.1 million. Approximately 5,380 m^2 (1.3 acres) of land would be required for the tanks.

The required treatment capacity for the Port of Long Beach is 1.0 million gallons per day. Capital costs for the facility are estimated at approximately $2.2 million. A basic outfall structure would cost about $100,000 assuming there are no permitting or environmental issues. The outfall could cost significantly more if discharge is not allowed directly into harbor waters.

The cost of onshore treatment at the Port of Long Beach is estimated to be $1.52/MT as shown in Table 5.2.

3.2.4 Port of Los Angeles

Operational Feasibility

Onshore ballast water treatment would be operationally feasible for the Port of Los Angeles if all vessels were retrofitted to allow for discharge to an onshore facility. The Port receives a large number of container vessels. Ballast water from these vessels likely could be discharged to a wharf without causing vessel delays.

The Port also receives bulk carriers, reefers and tankers, however, and it may not be possible for these vessels to transfer ballast water ashore at rates required for vessel loading without causing delays. The other components of onshore treatment would be operationally feasible for the Port. Wharves could be retrofitted and storage tanks, a treatment facility, and outfall could be constructed.

Estimated Costs

The total capital costs for onshore treatment at the Port of Los Angeles are estimated at $49.8 million as shown in Table 5.1. Total annual operation and maintenance costs are estimated at $223,000. The estimated capital costs for the onshore treatment components are discussed below and summarized in Table 5.1.

The Port of Los Angeles would require 41.2 kilometers of pipeline to connect the wharves to a single treatment facility at an estimated cost of $27 million. This analysis assumes pipelines would not cross channels, as such crossings are expensive. However, a more detailed economic analysis would be required to evaluate the cost effectiveness of constructing channel crossings verses using greater lengths of onshore pipeline.

The Port would require a total storage capacity of 40.6 million gallons. Eight 7.3-meter tall, 58-meter diameter, steel tanks would cost approximately $20.4 million. Approximately 21,000 m^2 (5.2 acres) of land would be needed for the tanks.

As discussed in Section 4.3.1, the required storage tank capacity is based on the maximum reported discharge in a single day. The maximum volume reported for one day at the Port of Los Angeles was 76,789 MT from two coal carriers and a container vessel. The next highest volume reported for one day was 40,151 MT discharged from two bulk carriers. The required treatment capacity for the Port of Los Angeles is 1.0 million gallons per day. Capital costs for the facility are estimated at approximately $2.2 million. A basic outfall structure would cost about $100,000 assuming there are no permitting or environmental issues. The outfall could cost significantly more if discharge is not allowed directly into harbor waters.

The cost of onshore treatment at Port of Los Angeles is estimated to be $1.37/MT as shown in Table 5.2.

3.2.5 Port of Oakland

Operational Feasibility

Onshore ballast water treatment would be operationally feasible for the Port of Oakland if all vessels were retrofitted to allow for discharge to an onshore facility. The Port receives primarily container vessels. Ballast water from these vessels could likely be discharged to a wharf-side system without causing vessel delays.

However, the Port also receives some breakbulk carriers, general cargo vessels, etc. and it may not be possible for some of these vessels to transfer ballast water ashore at rates required for cargo loading without causing delays.

The other components of onshore treatment would be operationally feasible for the Port. Wharves could be retrofitted and storage tanks, a treatment facility, and outfall could be constructed.

Estimated Costs

The total capital costs for onshore treatment at the Port of Oakland are estimated at $21.5 million as shown in Table 5.1. Total annual operation and maintenance costs are estimated at $150,000. The estimated capital costs for the onshore treatment components are discussed below and summarized in Table 5.1.

The Port of Oakland would require over 24.1 kilometers of piping to connect the wharves to a centralized facility. This would cost approximately $15.8 million and does not consider the cost of avoiding existing underground utilities.

The Port would require a total storage capacity of 7.3 million gallons. Two 7.3-meter tall, 50-meter diameter steel tanks would cost approximately $3.8 million. Approximately 3,927 m^2 (0.97 acres) of land would be required for the two tanks.

The required treatment capacity for the Port is 0.2 million gallons per day. Capital costs for such a facility are estimated at approximately $1.8 million and annual operating costs would be approximately $150,000. All vacant Port land is allocated for future development so land is not available at the Port for a storage/treatment facility. A basic outfall structure would cost about $100,000 assuming there are no permitting or environmental issues.

The cost of onshore treatment at Port of Oakland is estimated to be $3.93/MT as shown in Table 5.2.

3.2.6 Port of Redwood City

Operational Feasibility

Onshore ballast water treatment would be operationally feasible for the Port of Redwood City if all vessels were retrofitted to allow for discharge to an onshore facility and vessel safety and schedules were not compromised by such operations. The Port receives primarily bulk carriers and it may not be possible for such vessels to transfer ballast water ashore at rates required for cargo loading without causing significant delays. The other components of onshore treatment would be operationally feasible for the Port. Wharves could be retrofitted and storage tanks, a treatment facility, and outfall could be constructed.

Estimated Costs

The total capital costs for onshore treatment at the Port of Redwood City are estimated at $7.6 million as shown in Table 5.1. Total annual operation and maintenance costs are estimated at $142,000. The estimated capital costs for the onshore treatment components are discussed below and summarized in Table 5.1.

Connecting the Port of Redwood City's wharves to a central facility would require approximately 2.4 kilometers of piping at an estimated cost of $1.6 million.

The Port of Redwood City would require a total storage capacity of 8.4 million gallons. Two 7.3-meter tall, 53-meter diameter, steel tanks would cost an estimated $4.3 million. Approximately 4,420 m^2 (1.1 acres) of land would be required for the tanks. However, land is not available at the Port.

The required treatment capacity for the Port is 0.1 million gallons per day. Capital costs for such a facility are estimated at approximately $1.6 million and annual operating costs would be approximately $140,000. A basic outfall structure would cost approximately $100,000 assuming that there are no permitting or environmental issues involved.

The cost of onshore treatment at Port of Redwood City is estimated to be $5.08/MT as shown in Table 5.2.

3.2.7 Port of Richmond

Operational Feasibility

Onshore ballast water treatment would be operationally feasible for the Port of Richmond if all vessels were retrofitted to allow for discharge to an onshore facility. The Port receives mostly bulk carriers and tankers.

The other components of onshore treatment would be operationally feasible for the Port. Wharves could be retrofitted and storage tanks, a treatment facility, and outfall could be constructed. However, there is no land available at the Port for a treatment facility.

Estimated Costs

The total capital costs for onshore treatment at the Port of Richmond are estimated at $10.9 million as shown in Table 5.1. Total annual operation and maintenance costs are estimated at $142,000. The estimated capital costs for the onshore treatment components are discussed below and summarized in Table 5.1.

The distance for piping between the wharves at the Port of Richmond is approximately 8.9 kilometers. Piping would cost approximately $5.8 million.

The Port would require a total storage capacity of approximately 6.6 million gallons. Two 7.3-meter tall steel tanks 47 meters in diameter would cost approximately $3,400,000. The land area required for the tanks would be approximately 3,462 m^2 (0.9 acres).

The required treatment capacity for the Port is 0.01 million gallons per day. Capital costs for such a facility are estimated at approximately $1.6 million and annual operating costs would be approximately $140,000. A basic outfall structure would cost about $100,000 assuming there are no permitting or environmental issues.

The cost of onshore treatment at Port of Richmond is estimated to be $8.29/MT as shown in Table 5.2.

3.2.8 Port of Sacramento

Technical Feasibility

Onshore ballast water treatment at the Port of Sacramento would be technically feasible with the constraint that it is unknown whether discharge of treated saline ballast water to the fresh water port would be permitted under NPDES. An alternative disposal method for the treated ballast water would be needed.

Operational Feasibility

Onshore ballast water treatment would be operationally feasible for the Port if all vessels were retrofitted to allow for discharge to an onshore facility and vessel safety and schedules were not compromised by such operations. The Port receives primarily bulk carriers and woodchip carriers.

The other components of onshore treatment, with the exception of the outfall, would be operationally feasible for the Port. Wharves could be retrofitted and storage tanks and treatment facilities. As indicated below, the Port would require multiple treatment facilities.

Estimated Costs

The total capital costs for onshore treatment at the Port of Sacramento are estimated at $7.9 million as shown in Table 5.1. Total annual operation and maintenance costs are estimated at $142,000. The estimated capital costs for the onshore treatment components are discussed below and summarized in Table 5.1.

The wharves at the Port are on both sides of the Sacramento River. Total piping of approximately 2.1 kilometers would require laying a pipeline under the River, which is not feasible. Therefore, two treatment systems would be required. The pipeline would cost approximately $1.4 million.

The Port of Sacramento would require a total storage capacity of 9.4 million gallons. Two 7.3-meter tall steel tanks 56 meters in diameter would cost approximately $4.8 million. Approximately 4,943 m^2 (1.2 acres) of land would be required for the two tanks. There is land available for the treatment system and/or storage tanks at the Port.

The required treatment capacity for the Port is 0.1 million gallons per day. Capital costs for such a facility are estimated at approximately $1.6 million and annual operating costs would be approximately $140,000. A basic outfall structure would cost about $100,000 assuming there are no permitting or environmental issues. It is unknown, however, whether discharge of treated saline ballast water would be allowed in the fresh water port.

The cost of onshore treatment per metric ton at Port of Sacramento is estimated to be $3.93/MT as shown in Table 5.2. For two treatment systems, the cost of treatment per metric ton of ballast water would likely be increased by approximately 75%. The increase in cost for multiple treatment facilities is not linear as most of the pipeline would be required regardless of the number of facilities.

3.2.9 Port of San Diego

Operational Feasibility

Onshore ballast water treatment would be operationally feasible for the Port of San Diego if all vessels were retrofitted to allow for discharge to an onshore facility and vessel safety and schedules were not compromised by such operations. The Port receives bulk carriers, car carriers, general cargo vessels, reefers, tankers, etc.

The other components of onshore treatment would be operationally feasible for the Port. Wharves could be retrofitted and storage tanks, a treatment facility, and outfall could be constructed.

Estimated Costs

The total capital costs for onshore treatment at the Port of San Diego are estimated at $14.1 million as shown in Table 5.1. Total annual operation and maintenance costs are estimated at $142,000. The estimated capital costs for the onshore treatment components are discussed below and summarized in Table 5.1.

Approximately 14.2 kilometers of pipeline would be required to connect the three terminal areas at the Port of San Diego to a central facility at a cost of approximately $9.3 million.

The Port of San Diego would require a total storage capacity of 6.0 million gallons. Two 7.3-meter tall, 45-meter diameter, steel tanks would cost approximately $3.1 million. Approximately 3,198 m^2 (0.79 acres) would be required for the two tanks. All land at the Port is occupied or planned for development and construction of the facility would displace other uses (Rita Depastina, *pers. comm.*).

The required treatment capacity for the Port is 0.1 million gallons per day. Capital costs for such a facility are estimated at approximately $1.6 million and annual operating costs would be approximately $140,000. A basic outfall structure would cost about $100,000 assuming there are no permitting or environmental issues.

The cost of onshore treatment at Port of San Diego is estimated to be $7.79/MT as shown in Table 5.2.

3.2.10 Port of San Francisco

Operational Feasibility

Onshore ballast water treatment would be operationally feasible for the Port of San Francisco if all vessels were retrofitted to allow for discharge to an onshore facility and vessel safety and schedules were not compromised by such operations. The Port receives mostly oil and chemical tankers and containerships.

Although some wharves could be retrofitted, it may not be possible to construct pipelines along the shoreline due to right-of-way issues. In addition, there is no land available for storage tanks or a treatment facility.

Estimated Costs

The total capital costs for onshore treatment at the Port of San Francisco are estimated at $16.6 million as shown in Table 5.1. Total annual operation and maintenance costs are estimated at $150,000. The estimated capital costs for the onshore treatment components are discussed below and summarized in Table 5.1.

Connecting the terminal areas at the Port of San Francisco to a central facility would require approximately 12.9 kilometers of piping. Disregarding the right-of-way issue, the piping alone would cost approximately $6.4 million.

The Port of San Francisco would require a total storage capacity of 12.4 million gallons. Three 7.3-meter tall, 52-meter diameter, steel tanks would cost approximately $6.3 million. Approximately 6,478 m^2 (1.6 acres) of land would be required for the tanks. There is no land available at the Port for a treatment facility. No land is available in the Port and a parcel would have to be purchased from a private party at a price of approximately $7,500/$m^2$.

The required treatment capacity for the Port is 0.2 million gallons per day. Capital costs for such a facility are estimated at approximately $1.8 million and annual operating costs would be approximately $150,000. A basic outfall structure would cost about $100,000 assuming there are no permitting or environmental issues.

The cost of onshore treatment at Port of San Francisco is estimated to be $4.67/MT as shown in Table 5.2.

3.2.11 Port of Stockton

Technical Feasibility

Onshore ballast water treatment at the Port of Stockton would be technically feasible with the constraint that it is unknown whether discharge of saline treated ballast water would be permitted under NPDES to the fresh water port. Alternative disposal methods may be possible.

Operational Feasibility

Onshore ballast water treatment would be operationally feasible for the Port if all vessels were retrofitted to allow for discharge to an onshore facility and vessel safety and schedules were not compromised by such operations. The Port receives mostly bulk carriers.

The other components of onshore treatment, with the exception of the outfall, would be operationally feasible for the Port. Wharves could be retrofitted and storage tanks and a treatment facility could be constructed.

Estimated Costs

The total capital costs for onshore treatment at the Port of Stockton are estimated at $12.6 million as shown in Table 5.1. Total annual operation and maintenance costs are estimated at $142,000. The estimated capital costs for the onshore treatment components are discussed below and summarized in Table 5.1.

Piping at the Port of Stockton would require approximately 8.2 kilometers of total piping at a cost of $5.4 million. The system would require either a pipeline under the San Joaquin River, or two treatment and storage systems. A river crossing could increase the piping cost by a factor of ten.

The Port of Stockton would require a total storage capacity of 10.9 million gallons. Two 7.3-meter tall steel tanks, 60 meters in diameter would cost of approximately $5.5 million. The land area required for the two tanks would be approximately 5,723 m^2 (1.4 acres).

The required treatment capacity for the Port would be 0.1 million gallons per day. Capital costs for such a facility are estimated at approximately $1.6 million and annual operating costs would be approximately $140,000. A basic outfall structure would cost about $100,000 assuming there are no permitting or environmental issues. It is unknown, however, if discharge of treated saline ballast water would be allowed in the fresh water port.

The cost of onshore treatment at Port of Stockton is estimated to be $8.01/MT as shown in Table 5.2. For two treatment systems, the cost of treatment per metric ton of ballast water would be increased by approximately 40%. The increase in cost for multiple treatment facilities is not linear, as most of the pipeline would be required regardless of the number of facilities.

1.04 CONCLUSIONS

This study has investigated the technical, operational and economic aspects of the onshore treatment option for control of aquatic invasive species introductions. Key findings are:

1. Technically, it would be feasible to retrofit vessels and wharves, construct onshore storage tanks and treatment systems and discharge treated water back to the ocean/bay, provided cost is not a consideration and the treatment standards for existing wastewater treatment systems can be assumed to be representative of the standards required for organisms in ballast water.

2. It would be feasible to treat ballast water discharged from retrofitted container vessels, but operational delays are likely for bulk carriers and tankers that discharge significant volumes of water while loading cargo. Operationally, it would not be possible to treat all ballast water discharged within the U.S. EEZ at onshore facilities without intermediary vessels or some other transportation system to collect ballast water which, at present, is discharged outside of ports with the purpose of reducing hull draft or avoiding delays in port. Safety would be a concern for at-sea transfers of ballast water.

3. Economically, capital infrastructure costs would range from $7.6 million to $49.7 million per port. Operation and maintenance costs would range from $142,000 to $223,000 per year. Therefore, onshore treatment of ballast water is likely to cost at least $1.40 per metric ton of ballast water treated and as much as $8.30 per metric ton for California ports, depending on port configuration and discharge volume. For ports in other states that handle a proportionally larger volume of bulk carrier and tanker traffic, the capital and operation and maintenance costs are expected to be higher. For comparison, the cost of ocean exchange of ballast water, which is currently required for ships entering California from outside the U.S. EEZ is approximately $0.02 to $0.10/MT (Dames & Moore, 1999; Oemcke, 1999).

For a detailed evaluation of the effectiveness of ballast water treatment options, a common technical standard against which the options can be measured is needed. The development of ballast water treatment technologies is at an early stage. At this time, a wide variety of shipboard options using physical and chemical treatment technologies are under consideration. While many are still in the conceptual stage, some pilot programs are being initiated. Given the stage of the development of ballast water treatment options, it is too early to consider significant investment in the onshore treatment option.

It is important to note that the calculations used in this study are order-of-magnitude calculations designed to determine if onshore treatment is potentially economically and operationally feasible and if additional in-depth investigation is warranted. If a port were to design an onshore treatment system, a detailed analysis of shipping and discharge patterns would be required. An in-depth, port-specific, analysis would include a detailed analysis of shipping and discharge patterns as well as a survey of vessel operators to accurately assess the required treatment capacity.

In summary, further research into ballast water treatment alternatives and the development of ballast water standards are needed before the onshore treatment option, or any other option, can be evaluated as the preferred, environmentally sound method for protecting the coastal environment from the threat of invasive species.

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GLOSSARY

AMC	Astoria Metals Corp.
AQIS	Australian Quarantine and Inspection Service; Australia's lead agency for ballast water issues
Ballast Water	Water carried in designated ballast water tanks (segregated tanks) or cargo tanks (non-segregated tanks) to control draft, trim, stresses, and stability
Berth	Space at a wharf where a ship docks or anchors; to bring a ship to a berth
Bilge Water	Water that collects in the lower part of the ship through leaks and shipboard operations; Not to be confused with ballast water
Biocide	Substance that kills living organisms
Breakbulk	Non-containerized loose cargo
Bulk Carrier	Vessel that carries dry bulk cargo, such as ore, coal, etc.
CAPA	California Association of Port Authorities
Capital Cost	Initial costs for construction, equipment, etc.
Charter Rate	Rate paid by a charterer for the use of a vessel
Containership	Vessel that carries containerized cargo
CWA	Clean Water Act
Deadweight	Vessel's carrying capacity including cargo, ballast water, fuel, freshwater, passengers, etc.
Deadweight Tons (DWT)	Tons of Deadweight (see above)
Deballast	Release ballast water by gravity flow or pumping
Demurrage	Charge levied by a vessel owner for the period a vessel is retained beyond the allocated time for loading/unloading
DFG	Department of Fish and Game (California)
Dockage	Charge for docking
Draft	Distance a vessel’s hull extends below the water line

Drydock	Floating or stationary dock in the form of a basin from which water can be emptied to perform maintenance or repairs on a vessel below the water line
Flow-Through Dilution	Diluting ballast water in a tank by pumping in seawater and allowing the displaced ballast water to overflow through vents or valves
Full-Tank Reballasting	Replacing ballast water with open ocean water by pumping ballast water out of a tank and refilling
GPM	Gallons per minute
IFR	Interim Final Rule (U.S. Coast Guard); Recommends voluntary at-sea exchange of ballast water
IMO	International Maritime Organization
In ballast	Vessel carrying ballast and no cargo
Invasive	Nonindigenous and tending to spread. Invasive species tend to displace native species.
List	Sideways tilt of a ship
MARAD	Maritime Administration (U.S.)
MARPOL	International Convention for the Prevention of Pollution from Ships
MEPC	Marine Environment Protection Committee
MGD	Million gallons per day
Micron	One millionth of a meter
MT	Metric Ton; Mass of one cubic meter of water (264.2 U.S. gallons)
mWs/cm^2	milliWatt second per square centimeter
NABS	National Ballast Water Survey
NANPCA	Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990
NBWIC	National Ballast Water Information Clearinghouse
NISA	National Invasive Species Act of 1996
NOBOB	No Ballast On Board; Vessels only carrying cargo and unpumpable ballast “slop’ in ballast tanks
Nonindigenous Species	A species that is not native to an area

NPDES	National Pollutant Discharge Elimination System; System implemented by RWQCBS regulating discharges to surface water bodies
NRC	National Research Council
Open-Ocean Exchange	Replace ballast water with open-ocean water
Outfall	Place where a sewer or drain discharges; Outfalls are regulated under NPDES
Pilotage	Fee paid to a vessel pilot
PMSA	Pacific Merchant Shipping Association
POTW	Publicly Owned Treatment Work
PSSO	Puget Sound Steamship Operators
Reefer	Refrigerated containership
Right-of-Way	Legal right to pass over property owned by another (such as roads, pipelines, etc.)
Ro-ro	Roll-On/Roll-Off; Vessel designed to carry vehicles, which are loaded and unloaded by being driven or rolled
RWQCB	Regional Water Quality Control Board
Salinity	Concentration of dissolved salts in water
SERC	Smithsonian Environmental Research Center
SFDD	San Francisco Dry Dock Inc.
SLC	State Lands Commission
SNAME	Society of Naval Architects and Marine Engineers
Specific Gravity	Ratio of the mass of an object compared to the mass of the same volume of water
SWRCB	State Water Resources Control Board
Tanker	Vessel that carries liquid cargo in bulk
TMDL	Total Maximum Daily Load
Trim	Tilt of a ship from bow to stern
USCG	United States Coast Guard

U.S. EEZ	United States Exclusive Economic Zone (Extends 200 miles from shore)
US EPA	United States Environmental Protection Agency
UV	Ultra-Violet
VLCC	Very Large Crude Carrier